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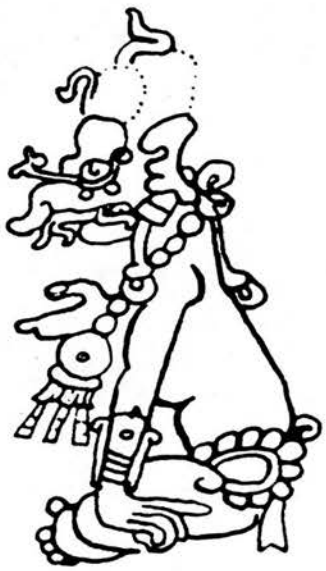
Holocene Environmental Change: A Palaeolimnological Study in Belize



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Abstract

This thesis reconstructs the environmental changes that have occurred in Belize over the last 10,000 years. The study focuses on two lagoons: New River Lagoon and Honey Camp Lagoon. Two key methodologies were employed: diatoms and stable isotopes (oxygen and carbon). Both ^{14}C and ^{210}Pb dating were used to provide a chronology. This work is the first detailed palaeolimnological study to be undertaken in Belize and consequently has enabled an improved understanding of climate dynamics in the circum-Caribbean. The Maya are the native peoples of Belize and this investigation provides an insight into their relationship with the environment in which they lived.

Lakes in Belize were sampled for water chemistry variables and modern diatoms. The lakes sampled follow a pathway of chemical evolution from calcium bicarbonate to sodium chloride-dominated systems. The chemical characterisation of the water bodies was not sufficient to enable a transfer function to be completed, but it is apparent that habitat also has an extremely influential role in determining the distribution of diatom species in the environments studied. Taxonomy is an issue which needs to be considered carefully when undertaking a diatom study in a new area. This was addressed through an investigation of the diatom species *Mastogloia smithii* var. *lacustris*. This study highlighted not only the role of the local environment in influencing species characteristics but also the differences between the features of type, published and modern material. The significance of these findings can only be judged with the collection of improved ecological data from all three sources.

In total, eight cores were analysed providing an overview of environmental change during the last 10,000 years. Older material has not been securely dated. It is apparent that the late Pleistocene was climatically very variable. The transition to the Holocene is marked by very poor diatom preservation and much drier conditions representing a clear shift in climatic conditions. Generally the climate of Belize during the Holocene has remained stable and moist. From c. 4900 years BP the isotope signal and diatom preservation become significantly more variable. Also during this time *Chenopodiaceae* pollen, which may represent disturbance by man increased. It is suggested that these factors are related, with climatic alterations occurring at the same time as the first potential signs of human activity in the area. The shift to late Holocene dry conditions was gradual, with the amount of pine pollen in the catchment increasing from c. 4800 years BP and oxygen isotopes showing a drying trend from c. 3000 years BP. There is also a significant increase in reconstructed conductivity values from the diatom data at this time.

The clearest signal for human activity is present in the core taken from near the archaeological site of Lamanai. Shifts in the carbon isotope record occur at c. 196 BC, c. AD 277 and c. AD 782-1192. These are coincident with the main periods of building activity in the area. Evidence has also been found for colonial activity at the time of logging at Hillbank (c. AD 1897-1917), and at the time of the sugar mill at Lamanai (c. AD 1862-1917).

Evidence has been found for the late Holocene dry period which has been linked to the collapse of the Mayan civilisation. The period around c. AD 850 is one of change in both lagoons. In Honey Camp Lagoon the oxygen isotope record shows a shift to drier conditions from 1250 years BP.

Declaration

This thesis is the result of my own work, where the work of others has been used it has been duly acknowledged.

Signed

Date 22nd March 2002

"During our short sojourn in Yucatan, we received vague, but, at the same time reliable intelligence of the existence of numerous and extensive cities, desolate and in ruins, which induced us to believe that the country presented a greater field for antiquarian research and discoveries than any we had yet visited."

J.L. Stephens 1843

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Chapter One: Introduction

1.1 Research Aims and Rationale

This investigation aims to improve both our understanding of human/environmental interactions in Belize and the regional climate dynamics of the circum-Caribbean. Evidence is presented from two lagoons:– New River Lagoon and Honey Camp Lagoon (Figure 1.1), both of which have documented archaeological sites on their shorelines.

To fulfil these aims the following research questions will be addressed:

1. How has the environment of northern Belize changed during the Holocene?
2. Does Belize fit into the known pattern of climatic change for the circum-Caribbean during the Holocene?
3. Can evidence be found for the late Holocene dry period - thought to have been influential in the collapse of the Mayan civilisation?
4. Can palaeoenvironmental records improve our understanding of human/climate interactions in Belize?

Previous studies in the circum-Caribbean have shown this to be a highly sensitive region to climatic change over a variety of time scales (e.g. Hodell *et al.*, 1991; Curtis *et al.*, 1996). In order to understand fully the dynamics of the circum-Caribbean it is very important to obtain records from the whole area. These can then be used to determine whether the area can be regarded as one climatic region through time. Knowledge of the archaeological history of Belize is well developed but this has not been related to wider themes affecting the region. This thesis will therefore place knowledge of human activity within an environmental context building on ideas highlighted by deMenocal (2001). Although studies have been carried out on the environments of Belize (e.g Pohl, 1990; Alcala-Herrera *et al.*, 1994; Rejmankova *et al.*, 1995) this is the first to investigate this aspect of Belize's environmental history, in detail.

This is a palaeolimnological study which uses evidence gained from lake sediments to answer the research questions posed. The two key methodologies employed are diatom and stable isotope analysis. Diatoms (siliceous algae) respond to variations in lake water chemistry and habitat. These changes can be the result of a number of factors, which are sometimes hard to differentiate. This is the first study of diatoms in Belize and therefore it is essential that a collection of modern flora be undertaken along with associated water chemistry data. This will enable not only the characterisation of the lake systems under investigation, but will also aid the successful interpretation of the fossil diatom records. The stable isotopes of oxygen provide a record of the balance between evaporation and precipitation. This, depending on the type of lake studied, is either a direct response to climate (e.g. in closed basins) or a record of changes to the groundwater/catchment that feed the system. The stable isotopes of carbon provide information about lake productivity which is influenced both by internal and external factors.

The use of stable isotopes and diatoms enables the characterisation of both the climate and the lake environment. Diatoms can also help to provide a record of human disturbance. Sediment geochemistry and magnetic susceptibility have been the focus of a parallel investigation providing complementary data (Furley *et al.*, unpublished). The data from that study provides additional evidence of human activity. Some pollen data from Hillbank, New River Lagoon have been provided by Professor Steve Blackmore (Natural History Museum, London) (Figure 1.1). These will be used to provide a background vegetational history of the area.

The following sections of this chapter concern the north of Belize and the sites which are the focus of this investigation. This thesis builds on the author's MRes studies where a diatom record from Hillbank, New River Lagoon was produced (Breen, 1998). This record showed a great deal of promise and therefore prompted the further investigation of the New River Lagoon. A number of other sites were investigated across Belize but most of these were found not to be suitable for further analysis. Honey Camp Lagoon matched the criteria set and was therefore selected for further study (see Chapter 4) (Figure 1.1).

1.2 Northern Belize

Belize is c. 290 km from north to south and c.100 km from east to west. It lies within the Tropic of Cancer at 16°-18°30'N and 88°-89°W, being bordered by Mexico to the north, Guatemala to the west and south and the Caribbean Sea to the east. Northern Belize comprises ridges of high, reasonably well-drained land and low swampy areas which generally drain to the sea by low-gradient rivers, such as the New River (Figure 1.1). These swampy areas run almost the whole length of northern Belize and are flooded for at least seven months of the year. Northern Belize is underlain by Tertiary and Cretaceous carbonates (primarily limestone) with a discontinuous mantle of Quaternary river alluvium. Karst development is less intense in north Belize than elsewhere on the Yucatan Peninsula (Johnson, 1983). There are three main geological faults in the north which trend NNE-SSW and these are demarcated by the New River, Booth River and the Rio Bravo (Wright *et al.*, 1959) (Figure 1.1). The main vegetation types in the north are pine ridge savanna on freely drained acidic soil and lowland broadleaf forest on calcareous deposits with loam or argillic soils. In the freshwater zones the environments are dominated by herbaceous swamps, seasonally flooded savanna and marsh forest. Mangrove forest occurs along the coast.

1.2.1 New River Lagoon:

Relatively little published information exists about the New River Lagoon. The lagoon is 35 km long and between 1-2 km wide. Johnson (1983) studied the New River (to which the New River Lagoon is connected), through an investigation based in Pulltrouser Swamp (Figure 1.1). Johnson's study provides valuable information on the factors affecting the New River Lagoon and on the dynamics of the nearby marshlands, which are a dominant ecosystem in north Belize. Northern Belize is characterised by surface as well as subsurface drainage. Thus, in Pulltrouser Swamp (and indeed all the other swamp systems in northern Belize) surface water and groundwater are inextricably linked. In times of rain, water either infiltrates directly

into the groundwater reservoir or flows as surface runoff into stream channels or directly into the swamp. Net gain (i.e. storage) of groundwater occurs in the wet season, while net loss occurs in the dry season. This loss, in Pulltrouser Swamp, is due to the nearly imperceptible draw of groundwater by the New River and by evaporation. These are thought to be of comparable importance.

The New River is not prone to frequent or excessive flooding because of the buffering effect created by the groundwater reservoir and also because it flows into the sea and therefore has open drainage. The swamp and the groundwater zones act as a sink for excessive rainfall, thereby attenuating the response of the river. Flow along the New River is very slow due to the dominant influence of groundwater over this system and the low gradient through which the river falls (Johnson, 1983). The broad floodplains of the river abound with ancient raised field complexes. The Lagoon has a relatively high sediment and mineral load. Erosion of the limestone scarp results in high carbonate deposition (Lambert and Arnason, 1978).

In summary, the New River Lagoon is a buffered site where the water level is mainly controlled by groundwater flow. This suggests that the isotope record produced will be a reflection of this, rather than the balance between evaporation and precipitation. The key piece of missing information is the residence time of the groundwater. Through the author's MRes studies it was apparent that the system has generally preserved diatoms through time (Breen, 1998). The New River Lagoon has a varied human occupation history which spans up to the present day. This will be discussed in Chapter 3.

1.2.2 Honey Camp Lagoon:

This lagoon is 3 km long and up to 2 km wide with an island of 200 m by 60 m. It is one of the largest freshwater lagoons in northern Belize. It is located at the headwaters of Freshwater Creek which is now a silted-up channel. It is not known when this drainage closed. Figure 1.2 shows a selection of maps from Belize dating from 1867-1952. In the maps dating from 1867 and 1888 the lagoon is not marked.

This suggests that this area may not have been thoroughly surveyed or that the lagoon may have been very different during that era. In 1938 it is mapped as being connected to Freshwater Creek, but by 1952 it is a separate system. A logwood company was set up at Honey Camp (Masson, 1993) in c.1938. The lagoon is also referred to in the literature as *Laguna de On*.

The area surrounding the lagoon is ecologically diverse, enabling knowledge to be gained on a wide range of the habitats and ecosystems found in north Belize. These include:

1. Karstic uplands which have well drained clay soils suitable for cultivation and are the location of high-canopy, tropical forest vegetation.
2. Low-lying sandy ridge savannas that are subject to seasonal innundation.
3. Sawgrass wetland swamps.
4. Inland mangroves.

(Wright *et al.*, 1959).

The annual rains in Belize cause water levels to rise and salinity levels of the lagoon system to change as the groundwater mixes with saline intrusions from the Caribbean Sea (Masson, 2000a). Honey Camp Lagoon is affected by this phenomenon, however the water is drinkable all year round (Masson, 2000a). This system is therefore also influenced by groundwater, but to a lesser extent than the New River Lagoon. One of the reasons behind the initial site selection was the fact that it is a closed basin and thus is likely to be more sensitive to climate change (reflected in the isotope record). The archaeology of the site is discussed in Chapter 3.

1.2.3 The Influence of Sea Level Variation:

Pohl *et al.* (1996) found evidence for changes in sea level through the investigation of soil profiles in Cobweb and Pulltrouser Swamps (Figure 1.1). Their study drew on a database of 40 radiocarbon dates that were calibrated using Stuiver and Reimer (1993). Sea level rose rapidly from 6000-4000 BC (5590-7140 ^{14}C years BP),

stabilising about 3000 BC (3620-4430 ^{14}C years BP), dropping slightly between 3000-1000 BC (3030-3620 ^{14}C years BP). This is when wetland agriculture was introduced (Turner and Harrison, 1983; Jacob, 1995). This lowering has been reported elsewhere in the Atlantic and Gulf of Mexico (Lighty *et al.*, 1982). Water levels began to rise again after 1000 BC (2750 ^{14}C years BP), with wetland fields becoming permanently abandoned at 200 BC (2300 ^{14}C years BP) when they were completely inundated throughout the year.

The magnitude of sea level rise in the last 7000 years is thought to have been about 3-4 metres. The freshwater aquifer in northern Belize, as elsewhere in the Yucatan, is floating on sea water and therefore any change in sea level would cause water levels in the interior to rise or fall. This is most clearly seen in the northern Yucatan Peninsula with the inception of lacustrine systems approximately 8000 years ago (e.g Whitmore *et al.*, 1996; Leyden *et al.*, 1998; Curtis *et al.*, 1998). Due to the low-lying nature of north Belize it would not be surprising if marine incursions played a role in the environmental history of the lagoon systems. If this were the case, then it is possible this signal would be recorded in diatom records.

1.3 The climate of Belize

In order to understand palaeoclimatic change, it is necessary to characterise the present day patterns of climate in the area of interest. If this is then placed in the context of surrounding regions it will enable the relationship between Belize and its neighbours to be more clearly understood, both in the present and the past.

Generally, the climate of Belize is tropical with a distinct dry season which runs from December to late May and a wet season which runs from June to November (Figure 1.3). There is a short dry period in August. The seasons are more pronounced in the north of the country than in the south, with northern Belize receiving a third of the rainfall that the south of the country receives (Esselman and Botes, 2001). The seasonal variability of temperature is much less marked with the mean monthly

temperature in Belize being 16-28 °C in the dry season and 24-33 °C in the wet season (Hartshorn *et al.*, 1984). The mean annual relative humidity is 83%.

The amount and distribution of rainfall is very important. Dahlin (1983) postulated that a severe drought of only a few decades could seriously deplete the supply of freshwater and render large portions of the Yucatan Peninsula uninhabitable. This is verified by the work of Pope *et al.* (2001) who found that as a result of the lack of surface water, it is groundwater discharge that has the main influence over the amount and distribution of wetlands on the Peninsula. If groundwater discharge was depleted then the region would be in serious difficulties.

The seasonal nature of the climate in the Caribbean region is tightly linked to the position of the Inter Tropical Convergence Zone (ITCZ). Due to the pattern of rainfall in the Northern Hemisphere tropics, it is the difference between the seasons that is of most influence to the climate dynamics of this area (Hastenrath, 1984). The rainy season occurs in the Northern Hemisphere's summer when the ITCZ moves north, displacing the North Atlantic subtropical high and weakening the easterly trade winds. This is also a time when the adjacent oceans are warm and atmospheric moisture is abundant due to the enhanced convergence and cloudiness over the Caribbean and the Atlantic. Conversely, the dry season occurs in the Northern Hemisphere winter when the ITCZ is located in the Southern Hemisphere. This is a time of cooler oceans and reduced atmospheric humidity (Hastenrath, 1984; Leyden *et al.*, 1993). The climate of Belize is determined by these atmospheric features and changes in their strength will therefore have important consequences.

Hodell *et al.* (1991) believe that changes in the balance between evaporation and precipitation are controlled by changes in the intensity of the annual cycle. These are modified in turn by long term insolation changes forced by orbital mechanics. The intensity of the annual cycle is defined by the difference between February and August insolation at 10°N, these are the months of maximum displacement of the ITCZ. Times of intense seasonality are associated with a northerly position of the ITCZ during the Northern Hemisphere summer which brings increased rainfall to

Central America. Hodell *et al.* (2001) have also found evidence for the role of solar forcing in influencing the climate of this region. This will be discussed in more detail in section 2.3.2.

There are two key weather systems which influence the climate of Belize; *northers* and *cyclones*. Northers are cold, wet, northeast air masses pushed to the south from November to February by Arctic air masses. The local effects of this phenomenon are cooler than normal temperatures, heavy rains and choppy seas. Cyclones are non-frontal, low pressure, large scale systems that develop over tropical waters. Depending on wind speed and sustainability, cyclones are classified as tropical depressions, storms or hurricanes. Hurricanes are the most powerful with minimum sustained winds of 119km/hour (Hartshorn, 1988). The rain which reaches Central America is often delivered by these violent thunderstorms and the yearly rainfall figures are very much influenced by tropical storms and hurricanes which provide a substantial amount of rain in a very short time period. Significant hurricanes occurred in 1931, 1955, 1961, 1974, 1978, 1998, 2000 and 2001 (Esselman and Botes, 2001).

One important aspect in the understanding of the climate of Belize is appreciating how it fits in with the rest of the region. Hastenrath (1976) determined that extreme weather conditions in the circum-Caribbean tend to come in sequences of several years, being either wet - such as the early and mid-thirties, and the mid-fifties to early sixties; or dry – such as the early to mid-forties and the late sixties to early seventies. A year can be classed as either wet or dry according to the shifts that are seen in the ITCZ and associated climate systems. During extreme dry years, departure patterns seem to be more pronounced than during extreme wet years (Hastenrath, 1976).

Figure 1.4 is a map of Belize with the average yearly rainfall boundaries. This clearly shows the rainfall gradient from north to south. The two key sites that are of interest to this study (Honey Camp Lagoon and New River Lagoon) are in two different zones with Honey Camp receiving 2032 mm year $^{-1}$ and the New River

Lagoon 1524 mm year $^{-1}$. The significance of this is that even though Belize is a small country, climatological differences exist which are likely to influence how areas respond to changes in climate dynamics through time.

The record of precipitation from Belize Airport shows that the average monthly rainfall during the period 1940-1998 was 151mm (Figure 1.5). From the early to late 1940s the levels are below average. The early 1950s were wet and the mid 1950s were dry. The period from the early to mid 1960s was wet. From the mid 1960s to early 1970s conditions were average or dry. From the 1970s to the early 1990s (with a brief departure in the late 1980s) the climate was wetter than average. This is only a very general trend as fewer measurements were taken during this time period. From the early 1990s average conditions have prevailed. This demonstrates that the precipitation values do vary through time and this is likely to be a response to external changes in the weather systems which govern the climate of Belize. Furthermore these distinct wet and dry periods match up with those specified by Hastenrath (1976). The periods of predominately wet conditions also coincide with hurricane activity. This is very important because it implies that presently the circum-Caribbean region acts as a coherent climatic unit

Figure 1.6 shows the records from Hillbank, Freshwater Creek and Belize Airport plotted on the same graph. Hillbank and Belize Airport show excellent agreement. There is very good agreement from 1940 to 1955 between Freshwater Creek and Belize Airport but in the late 1950s Freshwater Creek demonstrates higher values. The reasons behind this change are unclear, but as there is no information on the errors associated with the measurements, the data should be treated with a degree of caution.

The five-year running means for the Central American sites were compared (Figure 1.6). The running mean was used so that the general trends could be delimited. Firstly the general level of precipitation in Belize is higher than in the Mexican Yucatan Peninsula and the Caribbean region and lower than in Guatemala which is as expected due to its geographical position. The two records from the Mexican

Yucatan Peninsula show very little variability during the 20th Century, but values in Merida were lower in the late 1800s. The key implications of these results relate to the nature of the environment of Belize and the relationship between different areas of the circum-Caribbean.

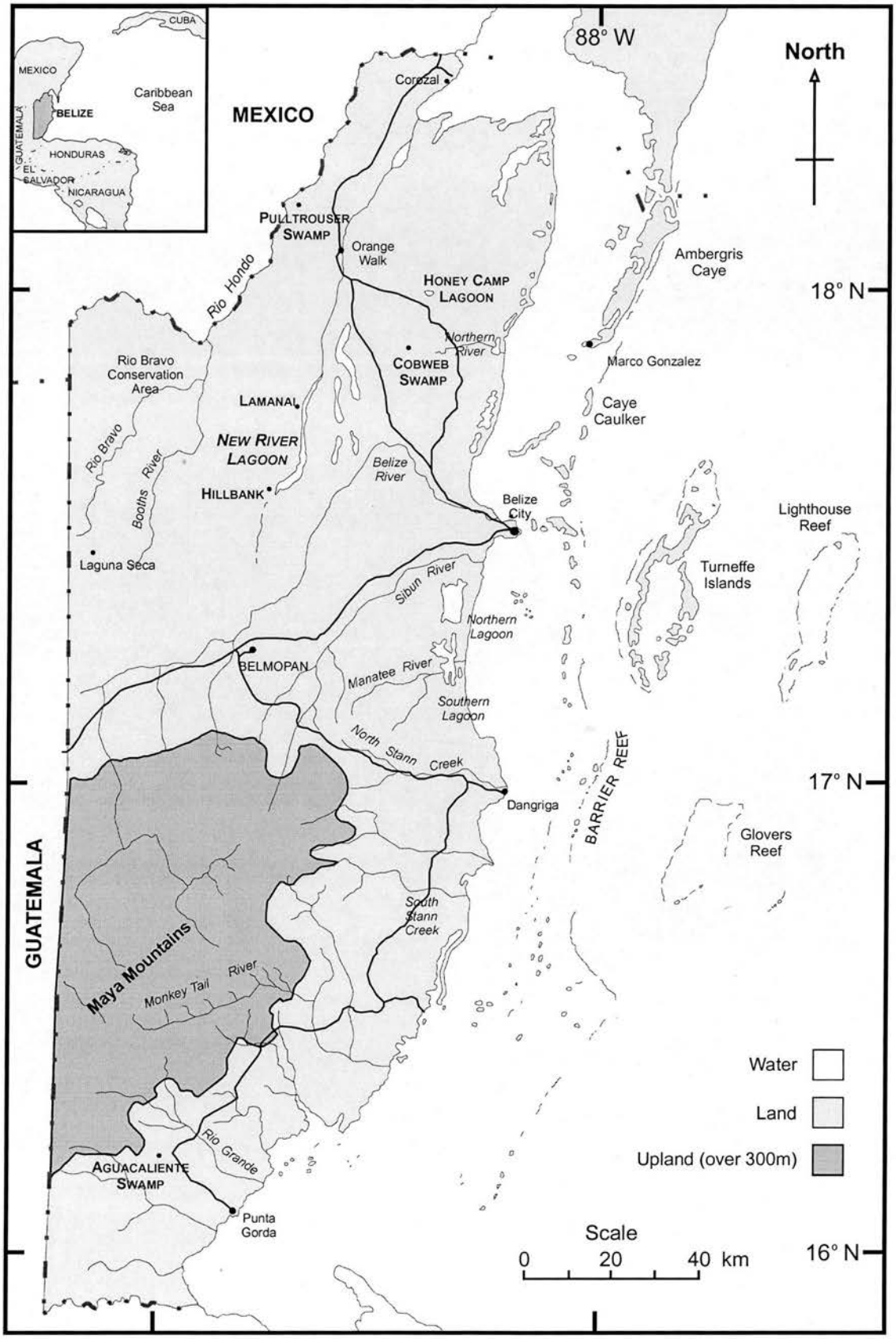
1.4 Thesis Outline:

This thesis is organised into nine chapters. The first chapter has provided an introduction by explaining the aims and research questions that have driven this investigation. Background information to the sites at the heart of this study is given, along with the present day climate dynamics of Belize. Chapter two focuses on the palaeoenvironmental records published for the circum-Caribbean region, these results are needed to unravel the records produced in this study. This is combined with a study of the mechanisms proposed as being responsible for climatic change in this region. Chapter three investigates what is known about the Maya, the native people of Belize. Knowledge of their society and how it evolved through space and time is of great interest to this study. Particular focus is given to the two lagoons where this study is based and to the other major sites in north Belize. Chapter four discusses in detail the field and laboratory methodology employed, including issues such as site selection. The two principal methodologies are discussed, with specific emphasis on issues that are of particular relevance to this thesis.

Chapter five is the first of the results chapters and deals specifically with the results from the modern environment. The results from the modern diatom and water chemistry study are described and analysed. Through Canonical Correspondence Analysis (CCA) and Detrended Correspondence Analysis (DCA) many of the water bodies in Belize have been characterised. This is twofold in its importance, firstly it provides valuable information on the diatom flora of Belize and the limnological characteristics of the water bodies; secondly, it allows for the meaningful interpretation of the fossil diatom records. Chapters six, seven and eight are the results and interpretation of the sites at the focus of the palaeoenvironmental study. Chapter nine provides a synthesis of knowledge gained from this research.

Methodological issues are discussed and future research directions are also considered in the final chapter.

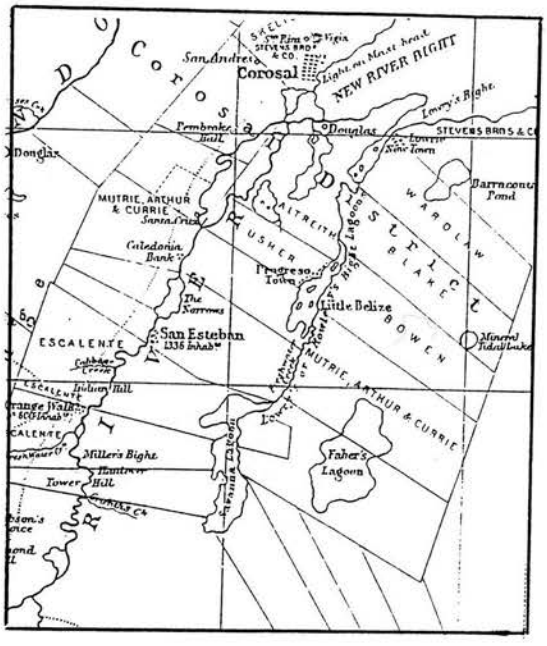
Figure 1.1



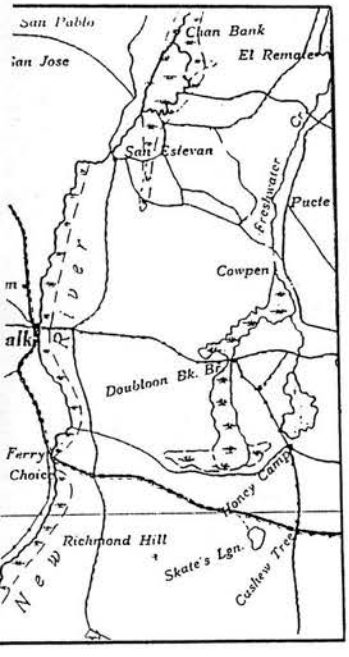
Based on maps published in Harsthorn et al. (1984) with additional information taken from the ITM 1:350,000 Series Sheet 230 (1993-1995 Edition).

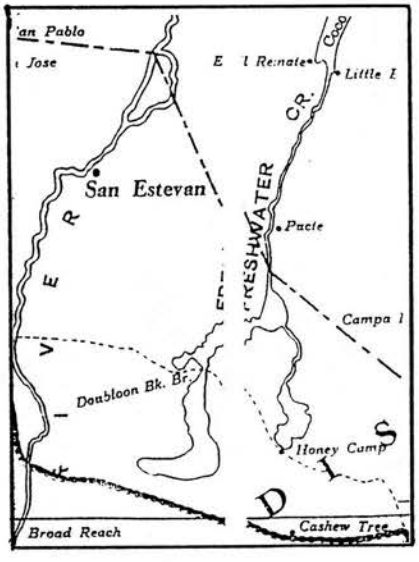
Modified from Murray (1995)

1888



1920





1938

1952

igure 1.2 Maps of Honey Camp Lagoon
Source: British Library map collection)

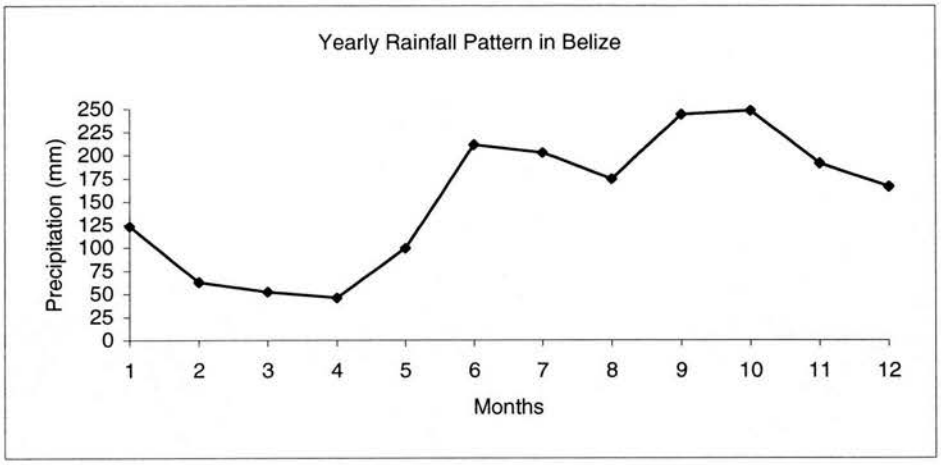


Figure 1.3
This figure illustrates the seasonal nature of precipitation in Belize. The data for this figure are from Belize airport (1940-1988).

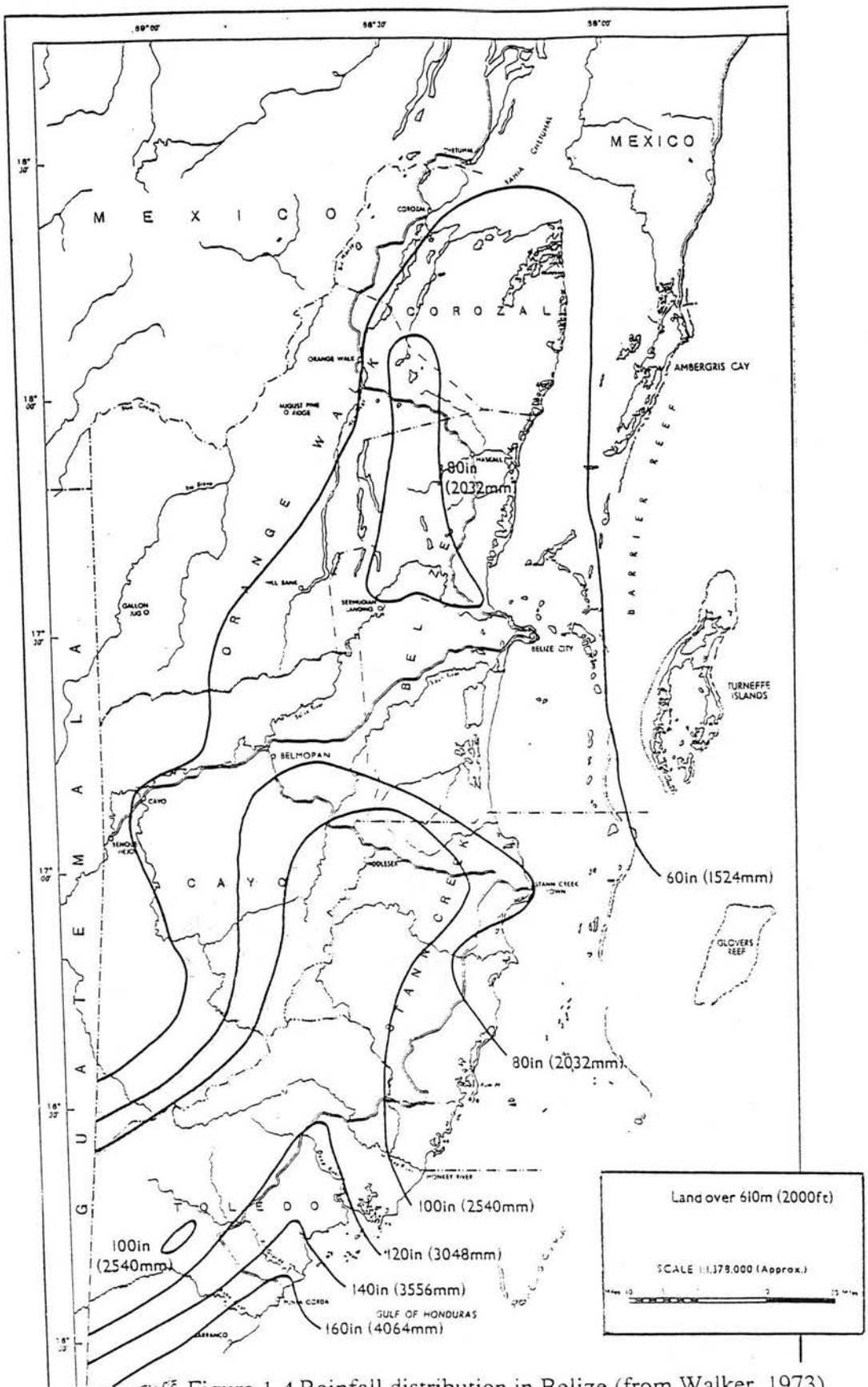
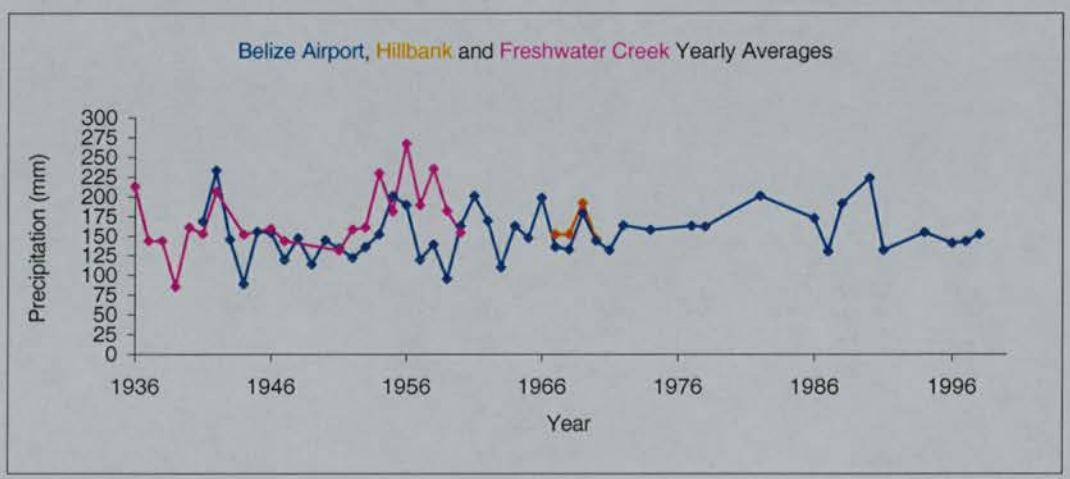
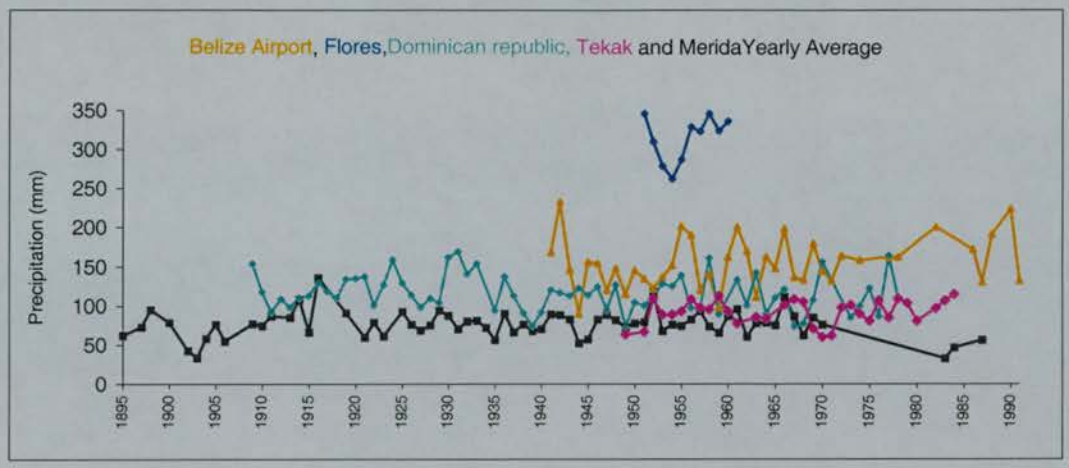


Figure 1.4 Rainfall distribution in Belize (from Walker, 1973)

Figure 1.5 shows the precipitation values that have been collected at Belize City Airport (University of Colombia, 2000). The data comprise monthly averages of precipitation in millimetres. Only years that contain all twelve months of data have been included and it is the average value for each year that has been plotted.



Only four complete years of measurement are available from Hillbank, New River Lagoon (1967-1970) (Walker, 1973). The nearest meteorological station to Honey Camp Lagoon is Freshwater Creek (figure 1.2). Precipitation is available from 1936-1960 at this site (Walker, 1973). These have been plotted with the Belize Airport data to determine whether this longer record can be used as an estimation of mean conditions throughout north Belize.



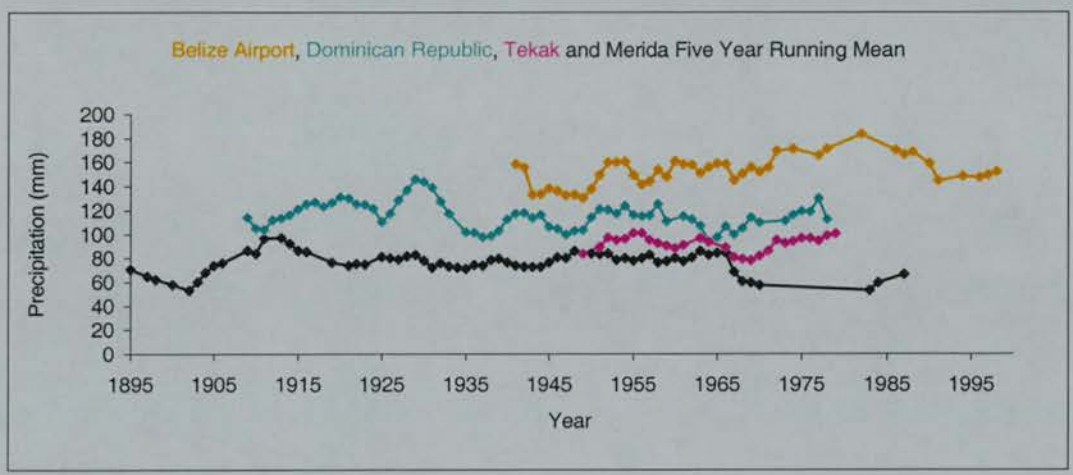


Figure 1.6
In order to gain an idea as to how the climate of Belize relates to key areas in Central America the precipitation records from the Dominican Republic, Flores (Guatemala), Tekak (south Yucatan Peninsula, Mexico) and Merida (west Yucatan Peninsula, Mexico) have been plotted. This provides important information with regard to the interpretation of the palaeoenvironmental records.

Chapter Two: Regional Patterns of Environmental Change

In order to place the records from Belize in context it is important to examine patterns of climatic change from the surrounding countries of Central America. Inevitably, humans have influenced the more recent parts of many of the records. These records are discussed in turn and the results are synthesised, enabling the key trends across the region to be highlighted. The location of the sites mentioned can be found in Figure 2.1. The mechanisms of climate change in Central America are discussed in the second part of this chapter.

2.1 The Yucatan Peninsula, Mexico

1. Location: Lake Coba, Quintana Roo State.
   Authors: Whitmore *et al.* (1996), Leyden *et al.*(1998)
   Proxies: Oxygen isotopes, diatoms.
   Altitude: < 25 metres a.s.l

- Lacustrine sedimentation in this basin began prior to 7600 ^{14}C years BP. This is coincident with the development of shallow lakes elsewhere on the Yucatan Peninsula, but later than the deep lakes of Guatemala. The lake being filled at this time was a response to both greater precipitation and a rising water table. The latter was probably a result of rising sea levels.
- This sediment sequence contains well defined banding which has been interpreted in other records as reflecting a strong seasonal influence on sediment composition and deposition. The thickness of the laminae suggests that they are however super-annual and reflect longer term cycles. Multi-decadal cycles in the levels of evaporation to precipitation were documented in the Late Holocene record by Curtis *et al.* (1996). This is therefore what might be reflected in this record.
- A eutrophication signal is present at the peak of the archaeologically documented urbanisation of the area. This suggests that a great deal of forest clearance and accelerated topsoil erosion occurred at this time (c AD 550-1000).

- Lake Coba is not as eutrophic or subject to as much human disturbance in the present day as it was in the past which provides an indication of how the activity of the Mayan people has changed through time.

2. Location: Lake Chichancanab,Yucatan State.
   Author: Covich and Stuiver (1974), Hodell *et al.* (1995), Hodell *et al.* (2001)
   Proxies: Oxygen isotopes.
   Altitude: 15 metres a.s.l

- The period from 22,000 to 8,000 ^{14}C years BP was characterised by major lake level fluctuations.
- Specifically, in the Lateglacial and early Holocene (before 8200 ^{14}C years BP) this area was a terrestrial environment reflecting dry conditions.
- At 8200 ^{14}C years BP the lake filled. This was related to the sea level rise associated with the last deglaciation.
- A rapid rise in lake level occurred at 7200 ^{14}C years BP when the $\delta^{18}O$ values decreased abruptly. Relatively wet conditions persisted between 7100 ^{14}C and 3000 ^{14}C years BP.
- Sea level continued to rise slowly after 6000 ^{14}C years BP, but the rate was insufficient to affect the lake level substantially during the middle to late Holocene.
- A drying trend was instigated at 3000 ^{14}C years BP with the interval from 2200 to 1200 ^{14}C years BP being extremely arid. The driest conditions occurred between 1300-1100 ^{14}C years BP which corresponds to the collapse of the Mayan civilisation.
- This record provides evidence of the effects not only of sea level but also of a clear late Holocene dry period. The records from this lagoon are of key interest because they reflect natural rather than human induced change of the landscape.

3. Location: San Jose Chulchaca, Yucatan State.
   Author: Leyden *et al.* (1996), Whitmore *et al.* (1996)
   Proxies: Pollen, diatoms, oxygen isotopes
   Altitude: 1-3 metres a.s.l

- The driest conditions in this sequence occurred around 6150 BC (> 7186 ^{14}C years BP) and over the next 1000 years the climate became increasingly wet.
- This trend was reversed between 5050 and 4050 BC (6121-5281 ^{14}C years BP). Although the lake waters were saline during this time period the climatic conditions were still considerably wetter than in the preceding millennium.
- The wettest period of the Holocene was at 3850 BC (5085 ^{14}C years BP) in this area.
- These conditions were rapidly reversed and drier conditions are detected around 3450 BC (4691 ^{14}C years BP).
- From 3450 BC to 1800 BC (4691-3519 ^{14}C years BP) the trend was to wetter conditions.
- From this point onwards drier conditions have prevailed to the present day.
- There is no evidence of human disturbance on this lake system, with the diatom record indicating oligotrophic to mesotrophic conditions throughout.
- This record lies on a climatic gradient with Lake Sayaucil and Lake Coba. San Jose Chulchaca receives the lowest annual rainfall and does not appear to have any archaeological evidence of sustained human settlement. This is the direct opposite to Lake Coba. The comparison of records along such gradients enables a great deal of useful information to be gained concerning the dynamics of an area.

The dates were converted to ^{14}C years BP from Stuiver and Pearson (1993) by the author of this thesis.

4. Location: Lake Punta Laguna, Quintana Roo
   Author: Curtis *et al.* (1996)
   Proxies: Oxygen isotope analysis
   Altitude: 14 metres a.s.l

- The patterns of change that are found in this 3500 year record, are decadal scale cycles of alternating wet and dry conditions which are superimposed on millennial scale shifts in mean climate conditions.
- The period from 3310 to 1785 ^{14}C years BP was wet.
- Dry conditions persisted between 1785-930 ^{14}C years BP. During this time, exceptionally arid events are recorded at 1510, 1171, 1019, 943, 559 ^{14}C BP.
- These coincide with two periods of key interest in Mayan history: the hiatus and the collapse. These are both periods of cultural discontinuity which had profound effects on the way in which Mayan society operated.
- By 1100 AD (942 ^{14}C years BP) more humid conditions returned. The next key dry period occurred between 1368 to 1429 +/- 50 cal years AD (651-506 ^{14}C years BP) which coincides with Mayan reports of famine, cold and drought and the simultaneous abandonment of cities in the Yucatan Peninsula such as Uxmal, Chichen-Itza and Coba.

The dates in the last time period discussed were converted to radiocarbon years from Stuiver and Pearson (1993) by the author of this thesis.

5. Location: Lake Sayaucil, central Yucatan Peninsula
   Author: Whitmore *et al.* (1996)
   Proxies: Diatoms and oxygen isotopes
   Altitude: 25 metres a.s.l

- Following the initial filling of the lake, water levels were low between 3050 to 2000 ^{14}C BP.
- The lake then rapidly became fresher as water levels rose. It was during this time frame that human disturbance is apparent in the watershed.

- Lake levels and human disturbance have remained fairly constant since this time.

There are a number of different factors which have influenced the amount of environmental change that is apparent in the sequences from the Yucatan Peninsula. In general terms the records follow the trends expected with a dry Lateglacial, moist mid Holocene and dry late Holocene. Complications arise in the interpretation of the sequences due to the influence of sea level and human impact on the systems.

2.1.2 Guatemala

1. Location: Lake Quexil, Peten Lake District.
   Authors: Deevey (1978), Deevey *et al.* (1983), Leyden (1984), Leyden *et al.* (1993), Leyden *et al.*(1994).
   Proxies: Pollen and oxygen isotope
   Altitude: 110 metres a.s.l

- This record provides valuable evidence about the climate changes that took place in this region before the transition to the Holocene, which is extremely useful in placing the records from later time periods in context.
- From 36-24,000 ^{14}C years BP the lake level was lower than today. The vegetation was much more temperate which suggests that the climate was cool and moist, with temperatures 4.7 to 6.5°C less than today.
- After 24,000 ^{14}C years BP an extremely dry period persisted with temperatures being 6.5 to 8°C cooler than today.
- With the onset of deglaciation around 12,500 ^{14}C years BP the dry climate conditions began to ameliorate.
- The lake filled rapidly after 10,500 ^{14}C years BP but the cool temperatures lingered averaging 3-4.7°C less than present.
- Lowland tropical forest did not properly form in the watershed until after the onset of warmer, moister conditions around 9000 ^{14}C years BP.
- Drier conditions are thought to have developed after 5000 ^{14}C years BP when the forest became less dense. This is however more likely to be due to human

influence on the system and the record after this point is clearly a cultural sequence, which limits the climatic inferences that can be made.

2. Location: Lake Peten-Itza, Peten Lake District
   Authors: Islebe *et al.* (1996a), Curtis *et al.* (1998).
   Proxies: Pollen and oxygen isotopes
   Altitude: 7 metres a.s.l

- This multi-proxy record suggests that in the earliest Holocene, prior to 9000 ^{14}C years BP, the climate was relatively dry.
- Water levels rose by 9000 ^{14}C years BP which is consistent with Lake Quexil which is just south of Lake Peten-Itza. Evidence from pollen indicates that widespread tropical forest had been established by 8560 ^{14}C years BP which is in line with the expected moist early Holocene conditions. The oxygen isotopes suggest, however, that the climate was relatively dry from 9000-6800 ^{14}C years BP.
- Records from other lowland tropical lakes reveal similar trends to both interpretations from Peten-Itza suggesting that neither reconstruction is anomalous (Leyden *et al.*, 1993; Vaughan *et al.*, 1985). It is likely that this juxtaposition was a result of the hydrologic budget of Peten-Itza exerting a greater control on lake water $\delta^{18}O$ than the regional evaporation/precipitation signal, hence the positive oxygen isotope signal during this time period.
- The oxygen isotope signal shows a steady and irreversible decrease beginning around 6800 ^{14}C years BP, suggesting a change from a wetland environment to a deeper lake. This occurred during the early to middle Holocene moist period that has been observed elsewhere. The concurrence of the $\delta^{18}O$ signal with the regional record at this point suggests that there has been a significant change in the controls over the lakes isotopic signature.
- The climate signal is confused from this point in the record due to the increasing influence of humans.

- Increased abundance of high forest taxa after 1000 ^{14}C years BP marks the recovery of the vegetation. This coincides with the time of Mayan collapse (see Chapter 3).
- This record is comparable to the records that have been produced for Lakes Quexil, Salpeten and Sacnab in Guatemala.

4. Location: Lake Salpeten, Peten Lake District
   Authors: Brenner (1994), Rosenmeier *et al.* (in press)
   Proxies Pollen and stable isotopes
   Altitude: 104 metres a.s.l

- Maya occupation of the watershed is marked by a decline in high forest and increased erosion beginning around 1400 BC (3118 ^{14}C years BP).
- From 1300-700 BC (3045-2469 ^{14}C years BP) there is a signal which may relate to a wet climate in this time frame.
- In AD 130 (1879 ^{14}C years BP) and AD 520 (1582 ^{14}C years BP), the times of the Preclassic abandonment and hiatus, there is a signal for decreased precipitation and forest recovery. These periods in Mayan history will be explained in more detail in Chapter 3.
- There is reduced soil erosion and a drying signal after AD 850 (1216 ^{14}C years BP) which coincides with the collapse of the Mayan civilisation.
- Forest recovery after AD 1400 (581 ^{14}C years BP) coincident with the time of final watershed abandonment.
- This record provides a clear indication of human activity during this time frame which may provide a general indication for the patterns in the surrounding regions.

The dates were converted to ^{14}C years BP from Stuiver and Pearson (1993) by the author of this thesis.

5. Location: Laguna Tamarindito, southwest Peten
   Authors: Dunning *et al.*(1998)
   Proxies: Pollen and gastropods
   Altitude: 120 metres a.s.l

- At the onset of the Holocene period the lake appears to be a deep water system due to the presence of deep-water gastropods.
- By 7500 ^{14}C years BP the region was colonised by tropical deciduous forest species indicating that the system was responding to the moist mid Holocene conditions.
- The lake experienced two periods of lower water levels between 6500 and 4900 ^{14}C years BP suggesting significant dry episodes.
- There is only equivocal evidence for significant drying of the local climate from 300 BC (2222 ^{14}C years BP).

The date in the last time period discussed was converted to radiocarbon years from Stuiver and Pearson (1993) by the author of this thesis.

The key difference between the Peten and the Mexican Yucatan Peninsula is the apparent amount of human impact that is recorded in the sequences. This may, however, be due to the reliance on pollen evidence in Guatemala. An understanding of how the records from the different proxies relate to one another is therefore essential to the correct interpretation of the sequences. The shift to lacustrine sedimentation in Guatemala occurred at the same time as the Yucatan Peninsula suggesting that the mechanism behind this change was regional. There is also evidence for change around 1000 years BP in these sequences.

2.1.3 Costa Rica

1. Location: La Chonta bog (Cordillera de Talamanca, south Costa Rica)
   Authors: Hooghiemstra *et al.* (1992); Horn and Sanford (1992); Horn (1993); Islebe *et al.* (1995); Islebe *et al.* (1996b) and Islebe and Hooghiemstra (1997).
   Proxies: Pollen and charcoal
   Altitude: 2430 metres a.s.l

- This record covers the Pleistocene, which was essentially a dry climatic interval in this area.
- The first pollen zone in this sequence represents the period from 80,000-50,000 years BP and provides evidence for four warm periods separated by three cold intervals. These episodes are thought to have been of regional importance.
- The second zone from 50,000-13,000 years BP is a stable period with a 7-8°C cooling at the time of the Last Glacial Maximum.
- Between 14,000 and 11,000 ^{14}C years BP moist montane oak forest was well developed in this region.
- During the Younger Dryas chronozone (11,080-10,500 ^{14}C years BP) a cool period is recognised in Costa Rica and has been given the name La Chonta stadial. A temperature drop of 1.5-2°C has been inferred in this time period and it coincides with a southerly shift of the northernmost position of the ITCZ. The change to warmer Holocene conditions was not a rapid one occurring between 10,400 and 9800 ^{14}C years BP.
- From 7000 to 4500 ^{14}C years BP, during the mid Holocene, the climate was increasingly humid. The period between 6000 and 5000 ^{14}C years BP was extremely stable with dense vegetation covering the area.
- Pollen of species which represent forest disturbance by humans, appear in the record from 4900 ^{14}C years BP.
- Dry conditions prevail from 4500-1500 ^{14}C years BP with two distinct dry periods during the Late Holocene: 2430 ^{14}C years BP and 1110-1180 ^{14}C years BP.

This record provides very clear evidence of a Younger Dryas interval in this region. This is important because it suggests that there are periods of climatic history where changes occur at the same time over a very wide area, but are manifested in different ways. In a similar manner to Guatemala and the Yucatan peninsula, the mid Holocene period was wet; dry conditions appear to occur earlier from 4500 years BP. This may however be an artefact of human impact on the system through vegetation clearance.

2.1.4 Honduras

1. Location: Lake Yojoa and Petapilla Swamp, western Honduras
   Authors: Rue (1987)
   Proxies: Pollen
   Altitude: 635 metres a.s.l

- This lake is located in the southeastern periphery of the Southern Lowlands (Figure 2.2) and therefore provides an interesting comparison with the human activity records from the Peten, Guatemala which is at the heart of this Mayan region.
- This sequence does not find any evidence for climate change during the late Holocene. The trends that are apparent appear to be due to human induced modification of the landscape.
- Clearance of natural vegetation appears to have occurred from 4500 ^{14}C years BP and from this point to 3000 ^{14}C years BP agricultural intensification is evident. After this phase until modern times there are few identifiable trends and the region appears to be ecologically stable.

2.1.5 Panama

1. Location: Laguna Volcan, Cordillera de Talamanaca, Panama
   Authors: Behling (2000)
   Proxies: Pollen and charcoal
   Altitude: 1500 metres a.s.l

- Evidence at 2860 ^{14}C years BP suggests that the landscape at this time was open within lower montane rainforest.
- The evidence of man is apparent through forest clearance throughout this record.
- *Zea mays* is found relatively late compared to other sites in Panama at 1790 ^{14}C years BP.
- Climatic changes such as the late Holocene dry period are difficult to identify due to widespread human impact.

2. Location: El Valle, lowland Panama (central Panama near the canal region)
   Authors: Bush and Colinvaux (1990)
   Proxies: Pollen.
   Altitude: 600 metres a.s.l

- The climate before 127,000 years BP was considerably colder than at present.
- 127,000-95,000 years BP was a period of near to present day temperatures in a warm and wet environment.
- The period from 95,000-50,000 years BP indicates cool, windy and dry conditions.
- From 30,000-10,000 years BP the climate was deteriorating and temperatures were 4°C lower than present. This may have been interrupted by a warm period. From 14,000 to 10,000 ^{14}C years BP a cooling of 5-6°C has been inferred.
- The warm and wet conditions of the present day were established in this record from 10,000-9000 ^{14}C years BP.

3. Location: Lake La Yeguada, (central Panama)
   Authors: Piperno *et al.* (1990), Piperno *et al.* (1991) and Bush *et al.*(1992).
   Proxies: Pollen, phytoliths and charcoal.
   Altitude: 650 metres a.s.l

- From 14,300-10,800 ^{14}C years BP the lake appears to be under a strongly seasonal regime which was manifested in fluctuating lake levels.
- The period between 13,000 and 10,000 ^{14}C years BP is recorded as being dry but increased precipitation and temperature conditions occurred from 10,800-10,500 ^{14}C years BP. The onset of these changes was abrupt and a new climate regime was fully established during this time frame.
- The early Holocene until 8600 ^{14}C years BP represents cooler and wetter conditions than at present. The rapid vegetation succession associated with Northern Hemisphere deglaciation ends by this point.
- There is evidence of a dry phase between 8200 and 5500 ^{14}C years BP with the period from 7000 to 5000 ^{14}C years BP representing a dry Holocene maximum.
- Human disturbance is also prevalent throughout the Holocene period.

4. Location: Gatun Basin, Panama Canal zone (central Panama)
   Authors: Bartlett and Barghoorn (1973).
   Proxies: Pollen
   Altitude: 30 metres a.s.l

- This is a record of sea level change, climate variability and human induced modification of the landscape.
- Temperatures from 11,300-9600 ^{14}C years BP appear have been at least 2.5°C cooler than today.
- From 9600-7300 ^{14}C years BP a well-developed mangrove swamp was deposited, which suggests that this was a time of marine influence on the system.
- From 7300-4200 ^{14}C years BP a transition from mangrove to freshwater swamp occurred due to a decrease in the rate of sea level rise. Seasonality along the Atlantic coast is thought to have been high at this time.

- All marine influence on the system ceased by 4200 ^{14}C years BP. This coincided with the development of agriculture resulting in the record from this point becoming an unreliable indicator of purely natural change.

5. Location: Lake Wodehouse, Darien (south Panama near the border with Colombia)
   Authors: Bush and Colinvaux (1994)
   Proxies: Pollen and diatoms
   Altitude: 500 metres a.s.l

- This record produces evidence for distinct climatic events in the last 4000 years.
- The key dry periods were from 3800-3700 ^{14}C years BP, 3400-2500 ^{14}C years BP and 1900 ^{14}C years BP to the present. These were not severe enough to cause the lake to fully dry out and are thought to be regional in their significance.

The records from this area highlight the influence of Pacific rather than Atlantic driven climate systems. The key manifestation of this is the dry conditions that prevailed in this area during the mid Holocene and the Younger Dryas signal which is characterised in this region by an increase in moisture and temperature. This is very different to the signal in Guatemala and the Caribbean. The impact of sea level is felt in this region which hinders the climatic interpretations that can be made. There is evidence for climatic drying in the late Holocene but these periods do not appear to be as severe as those found further north.

2.1.6 Haiti

1. Location: Lake Miragoane, (south Haiti)
   Authors: Hodell *et al.* (1991), Brenner *et al.* (1994), Higuera-Gundy *et al.* (1999)
   Proxies: Oxygen isotope and pollen data.
   Altitude: 20 metres a.s.l

- The oxygen isotope and pollen records indicate a dry climate from 10,500 to 10,000 ^{14}C years BP. This interval forms the latter part of the Younger Dryas chronozone where cold conditions returned to Europe and North America.
- From 10,000 to 7000 ^{14}C years BP there is a general trend to higher lake levels and more humid conditions, with decreasing salinity and increasing temperatures. This trend is not smooth and two key wet periods are noted at 9100 and 8100 ^{14}C years BP. The rising water level is attributed to both increased precipitation and rising sea level. Although water level was generally rising during the early Holocene, the ratio of evaporation to precipitation was still high between 10,000 and 8400 ^{14}C years BP. The pollen data also indicates widespread dry conditions until 8200 ^{14}C years BP.
- Lake levels were high between 7000 and 5300 ^{14}C years BP.
- Evaporation increased slightly to precipitation at 5200 ^{14}C years BP but lake levels remained generally high between 5200 and 3200 ^{14}C years BP.
- Greater fire frequency occurred in the moist mid Holocene. This was because although seasonality was at a maximum the early Holocene, it remained high into the mid Holocene. This resulted in there being large amounts of forests and dry winters.
- Between 3200 and 2400 ^{14}C years BP there is a two step increase in $\delta^{18}O$ indicating a trend to lower lake levels and increased aridity. The key dry period lasted from 2400 to 1500 ^{14}C years BP, but, this may include a temporary increase in moisture around 1700 ^{14}C years BP.
- Wetter conditions are found between 1500 and 900 ^{14}C years BP. These have been followed by a general increase in aridity until the present day.

2.1.7 Jamaica

1. Location: Wallywash Great Pond
   Authors: Street-Perrott *et al.* (1993) and Holmes *et al.* (1995)
   Proxies: Oxygen isotope
   Altitude: 7 metres a.s.l

- From 120,000-106,000 years BP the climate was humid and warm in Jamaica. This was a complex episode that encompassed three successive lacustrine episodes.
- The second warm and humid phase was prolonged and stable and lasted from 106,000-93,000 years BP.
- Cold and arid conditions combined with lower sea levels during the Middle and Upper Pleistocene caused the lake to desiccate.
- The Holocene consisted of alternating wet and dry conditions. The three highstands during the Holocene were at 10,000, 4400 and 1200 ^{14}C years BP and were a response to a wetter climate and rising sea levels. The $\delta^{18}O$ values at these times indicate that the precipitation/evaporation levels were moderately high.

2.1.8 Bahamas

1. Location: Church's Blue Hole, Andros Island, northwest Bahama Archipelgo.
   Authors: Kjellmark (1996)
   Proxies: Pollen and Charcoal
   Altitude: not given

- This record provides preliminary evidence for a period of dry climate prior to 4630 ^{14}C years BP when the rest of the Caribbean was wetter than at present.

- A second dry period is noted and is tentatively dated from 2980 ^{14}C years BP until 1530 ^{14}C years BP. Human impact is clear in the record from 740 ^{14}C years BP with a peak in charcoal concentration at this point.
- The patterns of pollen and charcoal also trace more recent environmental change related to the documented movement of peoples on the island.

In order to ensure that this review is truly regional for the whole of the circum-Caribbean it is important that both the Florida Peninsula and north Venezuela are considered.

2.1.9 The Florida Peninsula

1. Location: Lakes Tulane and Sheelar, South-central Florida
   Authors: Watts and Hansen, 1994
   Proxies: Pollen
   Altitude: 36 metres a.s.l

- Full glacial conditions in this area are characterised by open vegetation and are different at all times from conditions exhibited in the Holocene even though there is variation throughout the Peninsula.
- Many lakes in Florida began to accumulate sediment for the first time around 8000 ^{14}C years BP as a result of rising sea level.
- Between 7000-5000 ^{14}C years BP pine became the dominant vegetation on the Peninsula as a result of the modern climate of predominantly summer precipitation being established in this time frame.

2.1.10 Venezuela

1. Location: Lake Valencia, north coast Venezuela
   Authors: Bradbury, 1979; Bradbury *et al.*, 1981; Binford, 1982; Leyden, 1985; Rull, 1996, Curtis *et al.*, 1999
   Proxies: Stable isotopes, pollen, sediment geochemistry and diatoms
   Altitude: 402 metres a.s.l

- From 12,600-10,000 ^{14}C years BP conditions were dry apart from a short lived eutrophic, freshwater event at 10,900 ^{14}C years BP.
- Effective moisture increased from 10,500-9800 ^{14}C years BP which matches the Younger Dryas chronozone.
- During the early to mid Holocene (8200-3000 ^{14}C years BP) conditions were moist. Within this time frame there were two periods of lower lake level from 7600-6700 ^{14}C years BP and 3300 ^{14}C years BP.
- By 2140 ^{14}C years BP the lake was experiencing lowered water levels and increased salinity. The interpretation of conditions over this period have changed through time.

2.2 How do the records compare?

For the Last Glacial Maximum, Leyden *et al.* (1993) inferred a 6.5-8°C drop in annual mean temperature for lowland Guatemala and dry conditions. These values agree well with those postulated for mountainous Costa Rica. The records from Costa Rica and Lake Miragoane, Haiti from glacial to Holocene transition suggests a gradual change to Holocene environmental conditions rather than the abrupt changes recorded in Greenland ice cores (Islebe and Hooghiemstra, 1997).

Early Holocene records all indicate either warm and wet or warm and dry conditions. The Caribbean and Mexican Yucatan Peninsula records show dry conditions from 10,000-8200 ^{14}C years BP and wet conditions from 8200-7000 ^{14}C years BP. This too is shown in the records from Guatemala, with moist conditions being established

around 9000-8000 ^{14}C years BP. Panama, however, was warm and wet from 10,000-9000^{14}C years BP and dry from 8200- 5500 ^{14}C years BP. This reflects the strong influence of the Pacific Ocean.

The mid Holocene appears to be moist in Costa Rica (7000-4500 ^{14}C years BP), the Caribbean (7000-5300 ^{14}C years BP) and the Yucatan Peninsula. The latter region has records showing wet conditions from 7100-3000 ^{14}C years BP, however, the record from San Jose Chuluchaca, Yucatan Peninsula has an intermittent dry period within this wet period from 6800-5270 ^{14}C years BP. Records from Guatemala and Panama during this time cannot be purely related to natural variation. Open forests, which many of the records show existed at this time, may not be a result of a drier climate, but due to the impact of man.

During the late Holocene conditions were dry. Costa Rica was dry from 4500-1500 ^{14}C years BP with two key arid intervals at 2700-2000 ^{14}C years BP and 1110-1180 ^{14}C years BP. Panama was dry from 3800-3700 ^{14}C years BP, 3400-2500 ^{14}C years BP and 1900 ^{14}C years BP to the present. The Caribbean region is dry from 3200-2400 ^{14}C years BP, 2400-1500 ^{14}C years BP and wet from 1500-900 ^{14}C years BP, and dry to the present. Curtis *et al.* (1996) provide evidence for decadal scale arid intervals in the Yucatan Peninsula from 1041-586 +/- 50 cal year AD.

The key dry period noted by Curtis *et al.* (1996) has been found in other records from Central America. Lake Patzcuaro, Mexico shows a strong drying signal from 1100-1200 ^{14}C years BP (Metcalfe *et al.*, 1994). The Zacapu Basin shows the same signal at 1000 ^{14}C years BP (Metcalfe, 1995). La Piscina de Yurira also shows signs of desiccation from 1500-900 ^{14}C years BP (Metcalfe *et al.*, 1994). Preliminary evidence also exists from Lake Zirahuen for a drying signal around 900 years BP (Davies, 2000). Horn and Sanford (1992) noted that 1180-1110 ^{14}C years BP was a time of increased fire frequency due to an arid climate. These connections are apparent over a wide geographical area. It has also been postulated that peaks in microparticle concentration in the Peruvian Quelccaya ice cap, that occurred in AD 535-665, 855-985, 1384-1410, can be regarded as a proxy for increased aridity in the

Andean Antiplano (Thompson *et al.*, 1988). This tentative correlation between records from the Northern and Southern Hemisphere's suggests that these events may be related to large-scale departures in atmospheric and oceanic systems.

2.3 Mechanisms of Climate Change:

It is clear that the modern-day weather patterns of Belize are characterised by distinctive seasonal cycles (section 1.3). In order to understand the changes to the climate of Belize through time, the controlling mechanisms governing the seasonal cycles need to be examined. These mechanisms operate on a variety of time scales and influence climate systems in a number of different ways. It cannot be assumed that the climatic changes of the past were caused by single forcing factors, it is however more likely that a number of different factors were involved.

In order to unravel the mechanisms of climatic change in this region a number of different factors need to be considered. Over long time scales, changes in orbital forcing are influential. Milankovitch developed the idea that variations in the earth's orbit and axis occur over three distinct cycles. These variations result in seasonal insolation changes that modify the intensity of the annual cycle and therefore influence the global climate including the circum-Caribbean (Hodell *et al.*, 1991; Leyden *et al.*, 1994). The manifestations of these changes are geographically specific. In the northern tropics dry conditions in the late Pleistocene and moist conditions during the early Holocene were, in part, a response to changes in both precession and tilt (Curtis and Hodell, 1993; Curtis *et al.*, 1998).

In the tropics of North America dry conditions in the Lateglacial have been noted in:

1. Florida (Watts, 1975)
2. Peten District, Guatemala (Leyden *et al.*, 1993; 1994; Brenner, 1994).
3. Panama (Bush and Colinvaux, 1990; Piperno *et al.*, 1990; Bush *et al.*, 1992).
4. Haiti (Hodell *et al.*, 1991; 1995; Higuera-Gundy, 1999; Curtis and Hodell, 1993)
5. Jamaica (Street-Perott *et al.*, 1993; Holmes *et al,* 1995)

The Younger Dryas is a key climatic event noted in records from higher latitudes (Lowe and Walker, 1997). Records from high latitude North Atlantic, Greenland and Europe all show a period of rapid warming from 13,000 to 12,600 ^{14}C years BP followed by an abrupt reversal to colder conditions at 11,000-10,000 ^{14}C years BP (Leyden, 1995). A change at this time has been noted in records from the Caribbean and the Gulf of Mexico, but of a different magnitude and extent to that shown in high latitudes (Leyden, 1995).

There are four records which cover this time period in Central America: La Chonta Bog, Costa Rica (Hooghiemstra *et al.*, 1992; Islebe *et al.*, 1995); Lake Quexil, Guatemala (Deevey *et al.*, 1983; Leyden, 1984; Leyden *et al.*, 1993; 1994; Brenner, 1994); Lake Miragoane, Haiti (Hodell *et al.*, 1991) and Lake La Yeguada, Panama (Piperno *et al.*, 1990; Bush *et al.*, 1992). These sites show a shift in climatic conditions during the Younger Dryas period. Both La Chonta Bog and Lake Quexil show a return to cooler conditions and an increase in moisture. The record from Lake Miragoane indicates a drier climate. Lake La Yeguada has a more ambiguous environmental signal showing an increase in moisture and warmer temperatures.

The key parameters enabling climatic links between high and low latitudes include: seasonality of insolation, tropical SSTs and sea level rise. During the Lateglacial the seasonality of insolation increased (Berger, 1978) causing an increase in precipitation associated with the annual movement of the ITCZ. The western tropical Atlantic and the southwestern tropical Pacific were 5°C cooler in the Lateglacial (Beck *et al.*, 1992; Guilderson *et al.*, 1994). It has also been found that SST fluctuations during the Lateglacial-Holocene transition correspond to sea level rise as a result of glacial meltwater inputs (Guilderson *et al.*, 1994). This cooling in North America, as a response to meltwater forcing in the North Atlantic, may have generated more persistent or more frequent incursions of winter cold fronts to Central America (Leyden *et al.*, 1994). This is compatible with cooler temperatures without a decrease in precipitation. Panama would have remained unaffected if the fronts only extended to Costa Rica as they do presently. In short, the Younger Dryas was a cool signal with an increase in precipitation occurring between 11,070-10,400 ^{14}C years

BP in Costa Rica and immediately prior to 10,300 ^{14}C years BP in Guatemala. The drying signal seen in Haiti occurred from 10,500-10,000 years BP.

The intensity of the annual cycle in the northern tropics reached a maximum during the early Holocene (Curtis *et al.*, 1999).

The early to mid Holocene was moist. This has been noted in:

1. Yucatan Peninsula, Mexico (Covich and Stuiver, 1974; Hodell *et al.*, 1991; 1995; Curtis and Hodell, 1993).
2. Peten District, Guatemala (Deevey *et al.*, 1983; Leyden 1984; Islebe *et al.*, 1996a; Curtis *et al.*, 1998).
3. Panama (Piperno *et al.*, 1990).
4. Costa Rica (Islebe *et al.*, 1996b).

During this period, due to changes in the earth's orbit, Northern Hemisphere summers were much warmer and winters were much cooler than at present. This led to the ITCZ travelling further north and south of its present-day maxima due to the large differences in insolation between the seasons. The consequences of this were wet conditions in low elevation sites in the northern tropics (Curtis *et al.*, 1999).

2.3.1 The Role of the Ocean:

It is apparent that the oceans play a significant role in modulating the climate of surrounding land masses. The strong marine influence over Central America suggests that changes in oceanic conditions should be reflected in the terrestrial record (Hastenrath, 1976).

The North Atlantic operates as a conveyor system with water moving northwards in the upper levels of the ocean, sinking around latitude 60°N to form a deep water mass known as North Atlantic Deep Water (NADW). The return limb of the conveyor transfers deep water to the southern oceans. At a global scale, it has been postulated that differences in salt concentrations between the Atlantic and Pacific

Oceans ultimately drive this global conveyor (Broecker *et al.*, 1985). The key issue is whether the ocean-atmosphere system has more than one mode of operation. The implication of a change to the system would be that the earth, under the same solar regimes, would have quite different climates (Broecker *et al.*, 1985). The role of glacial meltwater from the North American Laurentide ice sheet is thought to be very significant as a mechanism for millennial scale climate changes such as the Younger Dryas. Periods of increased freshwater flow to the North Atlantic occurred at the same time as reductions in the formation of NADW (Clark *et al.*, 2001).

Recent evidence from the Bahama Banks suggest that both deep (NADW) and glacial North Atlantic Intermediate Water (NAIW) form. These two states wax and wane alternatively over orbital and millennial time scales (Marchitto *et al.*, 1998). The replacement of NADW by a less efficient system such as NAIW would have far-reaching implications for global climate. For example, if NAIW were to form during glacial conditions cooler SSTs in the tropics would result, as suggested by data from Barbados and Brazil (Webb *et al.*, 1997).

It has also been postulated that on longer time scales the Pacific and Atlantic Oceans had an equally significant role in producing millennial scale climatic cycles. This idea focuses on the fact that unstable ocean-atmosphere interactions in the tropical Pacific change tropical Pacific SST distribution. The locus of atmospheric convection lies over the warmest waters and therefore would have to move simultaneously. Moving this convection centre alters telecommunication patterns and therefore has far-reaching implications (Cane, 1998).

The El Nino-Southern Oscillation (ENSO) cycle is the most familiar instance of instability in the tropical Pacific with global implications. The ENSO cycle is sensitive to the seasonal cycle in the tropics and is therefore likely to be influenced by orbital variations (Cane, 1998). It has been found that increases and decreases in ENSO warm/cold events occur as a result of modelled changes in orbital insolation. Changes in the mean position of the warmest SSTs accompany these variations (Cane, 1998). ENSO, and variability in the subtropical North Atlantic high sea level

pressure (SLP), are known to affect rainfall in the Caribbean region (Giannini *et al.*, 2001).

It has also been found that atmospheric circulation is shaped by the competition between the sea level pressure system associated with the North Atlantic subtropical high and the eastern Pacific ITCZ. These influence air mass convergence on seasonal and interannual timescales. Anomalously high SLP in the region of the North Atlantic high translates into stronger trade winds, cooler SSTs and less Caribbean rainfall (Giannini *et al.*, 2000). Studies have also shown that rainfall in the Caribbean is dependent on the interaction between SST anomalies in the tropical Atlantic and the tropical eastern Pacific. An example of this is the rainy season in lower Central America, which starts early and ends late in those years beginning with warm SSTs in the tropical North Atlantic. The end dates are also delayed when the eastern equatorial Pacific is cool (Enfield and Elfaro, 1999).

The tropical Atlantic region unlike the tropical Pacific, is not dominated by any single mode of climatic variability (such as ENSO) rather, it is subject to multiple competing influences of comparable importance (Sutton *et al.*, 2000). The interactions between oceans and the atmosphere need to be examined further to enable the climate of the circum-Caribbean to be better understood.

2.3.2 The Late Holocene Dry Period

One of the central aims of this study is to reconstruct the climatic changes that have occurred in Belize through time. One of the key events which ties climatic and human history together in the circum-Caribbean is the late Holocene dry period. Evidence for this event has been found in a wide range of sites (e.g. Horn and Sanford, 1992; Metcalfe 1995; Curtis *et al.*, 1996) and has been implicated in the collapse of the Mayan civilisation, which occurred about AD 850 (e.g. Hodell *et al.*, 1995; Curtis *et al.*, 1996). Research efforts have concentrated on defining the extent and intensity of this drought rather than the causal mechanisms behind it.

The drought is part of a general drying trend which occurred in this region from 3000 ^{14}C years BP onwards (Curtis *et al.*, 1999). This general trend is thought to have been caused by a reduction in the intensity of the annual cycle whereby the perihelion shifted to the winter resulting in warmer conditions, and the aphelion shifted to the summer resulting in cooler conditions during the respective seasons. The movement of the ITCZ was, therefore, restricted and precipitation amounts declined (Curtis *et al.*, 1999).

Hodell *et al.* (1991, 1995) determined that the main driving mechanism behind the climate changes seen in Haiti and the Mexican Yucatan Peninsula were due to orbital forcing and the subsequent affects on the intensity of the annual cycle. The authors did not believe that the abrupt shift to dry conditions c.1000 years BP could be explained by this mechanism. Curtis *et al.* (1996) however suggest that the short-term variability in precipitation and evaporation balance shown in their record is a result of large-scale departures in atmospheric and oceanic circulation which must ultimately be due to orbital forcing. Brenner *et al.* (2001) suggest that there must be other, as yet unexplained, forcing factors which are at work in this region.

The drought occurred in both Central America, the Sahel (Street-Perrott *et al.*, 2000) and Ethiopia (Bonnefille and Mohammed, 1994). This linkage is not surprising because both regions are influenced by the seasonal migration of the ITCZ (Hastenrath, 1976). Over the last century, variations in Sahel rainfall have been correlated with the degree of temperature contrast between the North and South Atlantic. Cold northern oceans and warm southern oceans are generally associated with dry years in the Sahel; Caribbean and Central America and vice versa (Hastenrath, 1991). Further explanations for the dry period include the reduced northward heat transport by the oceans as a result of either the freshening of the water column or feedback processes stimulated by changes in tropical land surface. Such events have been found to occur during the summer in the tropics and during the winter at temperate latitudes in association with cooler SSTs in the North Atlantic (Lamb *et al.*, 1995).

Variations in the output from the sun are well established to have a major influence on climate change (Van Geel *et al.*, 1998). GCM simulations suggest that a 2% decrease in solar output would result in a 4°C drop in earth surface temperatures (Hansen *et al.*, 1984). The principal mechanism through which the output from the sun varies is through sunspots. Observations over the last two centuries have confirmed that these have a periodicity of ~11 years (Harvey, 1980). Furthermore it is thought that higher levels of solar activity increase the strength of the solar wind (the stream of protons and electrons emitted by the sun), which deflects cosmic rays and results in a decrease in the production of cosmogenic isotopes. (Van Geel *et al.*, 2000). This has direct implications for the amount of ^{14}C which is produced.

In the most recent record which has been produced from Lake Chichancanab, Yucatan Peninsula, Hodell *et al.* (2001) discovered a 208-year cyclicity in the $\delta^{18}O$ record. This has also been identified in the record from Lake Punta Laguna, Yucatan Peninsula and fits well with the 200-year cycle isolated in the Cariaco Basin. This latter cycle has been attributed to solar forcing. A 206 year cycle is apparent in records of cosmogenic nuclide production. The $\delta^{18}O$ record from Lake Punta Laguna has been compared to ^{14}C production records and for the last 2000 years they appear to be negatively correlated with times of higher $\delta^{18}O$ values coinciding with lower ^{14}C production. This implies that the late Holocene dry period occurred during a period of increased solar activity. Changes in solar output are believed to affect global mean temperature, humidity, convection and the intensity of Hadley Circulation in the Tropics (Hodell *et al.*, 2001). As demonstrated earlier, mean annual rainfall varies significantly throughout the Yucatan Peninsula and thus any change to the position of the Hadley Circulation or tropical convective activity is likely to affect rainfall patterns (Hodell *et al.*, 2001).

It is also possible that the late Holocene dry period could be the result of internal changes to the system such as volcanic eruptions. Evidence has been found for an eruption of El Chichon between AD 676-788 which could have been partly responsible for the climatic drying seen in AD 800-1000. El Chichon has erupted frequently over the last 8000 years and therefore it could have played an important

role in the development of environmental conditions in this area (Espindola *et al.*, 2000).

2.3.3 Summary

The mechanisms behind climatic change appear to be interrelated, with a variety of different forcing factors operating over a number of time scales. This has resulted in certain mechanisms having greater, lesser or even different implications for relatively nearby areas. This is especially important when considering the climates of North, Central and South America.

On longer time scales it is apparent that orbital forcing has a profound influence on how wet or dry the climate is. Climates of Central America were directly influenced by the end of the Pleistocene glacial period through the input of meltwater into the oceans. This influenced both ocean and atmospheric processes. The climate of the Holocene was relatively stable. However, changes in the late Holocene have been more abrupt in nature and the forcing mechanisms behind these are not as clear. One of the most recently proposed ideas is solar forcing. In summary, the climate of Belize is affected by two key factors: the prevailing subtropical wind system and the associated ocean circulation patterns (particularly in terms of fluctuating SSTs).

2.4 The Impact of humans on the Environment

It is apparent that the signal of climate-induced variability is blurred by the influence of humans on their environment. This makes it difficult to differentiate which factors are forcing change. There are three main ways in which this issue can be addressed. A detailed history of human occupation and activities can be gathered from archaeological and documentary sources. This will allow the results gained to be placed against a background of information which may enable a climate signal to be teased out. Alternatively, only sites that are free from human occupation could be studied which would ensure that any environmental fluctuations are climatically

induced. Alternatively, proxies such as oxygen isotopes could be employed which respond mainly to climatic forcing.

The evidence for human impact is plentiful in the northern tropics (Deevey 1978; Deevey *et al.*, 1979; Vaughan *et al.*, 1985; Leyden, 1987; Rue, 1987; Bush *et al.*, 1989; 1992; Hansen, 1990; Piperno *et al.*, 1990; Bush and Colinvaux, 1994; Northrup and Horn, 1996). These impacts are not just restricted to modern human activity. For example O'Hara *et al.* (1993) convincingly showed that the impact of traditional agricultural methods was just as destructive to the environment as the plough agricultural systems introduced by the Spanish.

One of the main problems encountered in the quest to unravel the impact of the Maya is that the chronological framework of lacustrine sequences is imprecise. Hard-water effects (Deevey and Stuiver, 1964) and the redeposition of carbonate-rich basin soils (Vaughan *et al.*, 1985) result in inaccurate radiocarbon dates. Relative chronologies have therefore been relied upon through the correlation of pollen and archaeological evidence (Vaughan *et al.*, 1985; Brenner, 1994). This process is hindered by the fact that pollen records are influenced by the activities of humans. This is especially influential when one considers that human impact is clear in Panamanian vegetation records from 11,000 years BP (Piperno *et al.*, 1991; Cook and Ranere, 1992). The oxygen isotope record was thought to have been a purely climatic signal, but dramatic changes to watershed hydrology may actually produce isotopic shifts (Brenner *et al.*, 1994; Rosenmeier *et al.*, in press). These points highlight that as much information as possible must be gathered from the area being studied, before conclusions can be drawn from the data sets.

The actions of humans will be influenced by the climate conditions within which they are found. Although it cannot be assumed that there is a causal relationship between climate change and the development of maize cropping, the latter occurred at the onset of drier conditions (7000 years BP). Increased seasonality (i.e. an augmented difference between the wet and dry season) and lower precipitation levels

would have expanded the range of exploitable habitats for cropping (Piperno *et al.*, 1991).

"....It appears that a major role for archaeologically inspired palaeoecology will be the provision of information on aspects of cultural process and change in tropical forests that is often difficult to extract from archaeological sites; dynamic environmental changes and their possible relationship to the evolution of subsistence strategies, organisation of labour and demographic trends". Piperno *et al.* (1991: 244). The key concept is therefore that the imprint of humans on their environment can be very significant and vice versa. This dynamic interplay needs to be unravelled before a true understanding can be gained of the environments in question.

2.5 Environmental Change Records from Belize

There is a paucity of knowledge concerning the environmental history of Belize compared to neighbouring countries in Central America. A variety of environments in Belize have been studied, but the work presented in this thesis is the first palaeoecological study of its kind to be undertaken. The information which has already been published on Belize, provides a useful framework into which this study can be placed.

Both the New River Lagoon and Honey Camp Lagoon are surrounded by marsh systems. Rejmankova *et al.*(1995) studied the freshwater wetland plant communities of northern Belize. The climate of Belize is dominated by its seasonality and thus, although the marshes are waterlogged all year round, it is thought that they must experience periods of desiccation over longer time scales (Rejmankova, *et al.*, 1995). Rejmankova *et al.* (1995) investigated the northern coastal plain within Orange Walk and Corozal districts of northern Belize (Figure 1.1). The hydrology of this area is not completely understood, but it is thought that the marshes are fed primarily by springs. Some surface runoff occurs during storms but this quickly enters the aquifer. The water table fluctuates in the order of 1m a year (Siemens, 1978) and the

water level in the marshes is about 20 cm higher in an average wet season (Rejmankova *et al.*, 1995).

In modern times, there has been no attempt to modify the marsh environment in this area. Marsh fires are, however, common due either to accidents as a result of burning cane fields or are deliberately started to gather fish and turtles (Rejmankova *et al.*, 1995). These marshes are not only important as the dominant ecosystem of the region, but they also have great archaeological significance. Through remote sensing techniques polygonal patterns have been distinguished in the marshes suggesting that the Maya utilised this environment for agriculture (Adams *et al.*, 1981). Most of the marshes cannot be cultivated today because dry-season water levels and soil salinities are too high (Rejmankova, *et al.*, 1995). Evidence suggests that ancient agricultural levels lie well below the modern marsh surface and the main period of activity was in the Preclassic Mayan period (2000 BC to AD 250). The subsequent rise in groundwater appears to have been the result of a rise in sea level (High, 1975) which ultimately resulted in the abandonment of the wetland fields (Pohl, 1990).

Two important wetland sites in Belize have been studied in great depth: Cobweb Swamp and Pulltrouser Swamp (Figure 1.1). An 8000 year record has been obtained from Cobweb Swamp which is the location of the Mayan site of Colha (Alcala-Herrera *et al.*, 1994; Jacob and Hallmark, 1996). Species of ostracods, foraminifera and molluscs were used to reconstruct salinity changes. This evidence suggests that there have been marked changes in salinity throughout the history of the swamp. The history of the site is as follows:

1. The period from 5630-4790 ^{14}C years BP was one of rising sea level that resulted in a marine influenced estuarine environment.
2. The rate of sea level rise began to decrease at 4790 ^{14}C years BP allowing the colonisation of marine tolerant species such as mangroves.
3. Deforestation in Cobweb Swamp began around 4500 years BP. This would have had a substantial affect on the swamp's hydrology. After 3370 ^{14}C years BP water levels began to rise again and a new freshwater lagoon formed. There are three reasons why this may have occurred:

- In humid areas, such as Belize, trees are the main evapotranspirative pumps in the system. If deforestation occurred in the Classic period when population levels were high then the formation of a freshwater system could have been the result. From 1700-1000 years BP population densities in this area reached 200-300 people/km^2 (Rice and Culbert, 1990).
- Substantial subsidence.
- The construction of a dam by the Mayan population.

4. There is no evidence of renewed sea level rise that would have had an impact on Cobweb Swamp after 3370 ^{14}C years BP.
5. The system stabilised and swamp vegetation formed after 520 ^{14}C years BP. The Mayan civilisation had collapsed by this point which meant that forest would have been able to develop (see Chapter 3).

(Alcala-Herrera *et al.*, 1994; Jacob and Hallmark, 1996).

In order to develop a regional perspective on the changes that have occurred in north Belize, Alcala-Herrera *et al.* (1995) compared the records from Laguna de Cocos, Albion Island with Cobweb Swamp. Laguna de Cocos has been a freshwater lake for almost 4000 years whereas, during this time Cobweb Swamp has changed from a mangrove community to a brackish and then freshwater swamp. At the present time, the limnetic Laguna de Cocos contrasts with the oligohaline Cobweb Swamp (Alcala-Herrera *et al.*, 1995). When the records are compared at 4820 ^{14}C years BP (which is the date for Laguna de Cocos), both systems show similar mesohaline environments. Neale (1988) defines these salinity classifications as follows:

- Mesohaline: 5-18‰
- Oligohaline: 0.5-5‰
- Limnetic: 0-0.5‰.

Hansen (1990) showed (using pollen evidence from Laguna de Cocos) that from 5000-6000 years BP a dense forest surrounded the lagoon with high concentrations of pollen suggesting that there was little erosion of soils into the lake. Both sites also record the presence of *Zea mays* in the period 3000-3500 years BP suggesting that they were both impacted upon by man at the same time. Pollen data show a transition

from a closed forest to an open, disturbed agricultural area with savanna. The system reverted back to forest after the collapse of the Mayan civilisation in approximately AD 850. The evidence suggests that at the climax population in Albion Island, maize was planted in monoculture (Pohl *et al.*, 1990).

There is a difference in the timing of the removal of marine influence between the two areas. Laguna de Cocos was free by 4700 years BP and Cobweb swamp by 4000 years BP (Alcala-Herrera *et al.*, 1995). This is not surprising as Cobweb Swamp is much closer to the sea than Laguna de Cocos and therefore its influence is likely to be much more pervading. Bradbury *et al.* (1990) attribute the freshening of Laguna de Cocos to the development of a moister climate at 5000 years BP. Alcala-Herrera *et al.* (1995) found evidence that present-day precipitation patterns were established 4000 years BP. The discrepancies between the two records are due to the poor chronological control and the different environments. Evidence for increased levels of moisture from 1700-1600 years BP and a drying trend around AD 1000 have been found which coincide with a drop in agricultural indicators (Bradbury *et al.*, 1990).

Pulltrouser Swamp has been extensively surveyed in terms of its vegetation, soils and Mayan history (Turner and Harrison, 1983). From this work a number of conclusions can be made. The region was undoubtedly affected high by sea level which stabilised at 2000 years BP (High, 1975). There is evidence of drier conditions before this time. The edges of the swamp show evidence for fluctuating water levels. The cause of this has not been determined as it could be due to human modification of the system or rainfall changes. It is thought, however, that major changes in rainfall would be needed to change appreciably the surface water characteristics (Turner and Harrison, 1983).

2.6 Conclusion

It would be problematic at the moment to relate our knowledge of climatic change in Belize to the rest of Central America with confidence, due to lack of dating control. General trends can be delimited though. Sea level rise appears to have been the main control on lagoonal stratigraphy in lowland northern Belize during the Holocene (Alcala-Herrera *et al.*, 1994). Its effect was also felt in the Mexican Yucatan Peninsula as it enabled the beginning of lacustrine sedimentation. There is also preliminary evidence for a drying trend in Belize c AD 1000. The effects of man are clear in the Belizian records through deforestation and the development of agriculture.

The information presented in this chapter provides an important context within which the results of this thesis can be placed. In order to understand the patterns of human development in Belize, the next chapter will discuss the Maya.

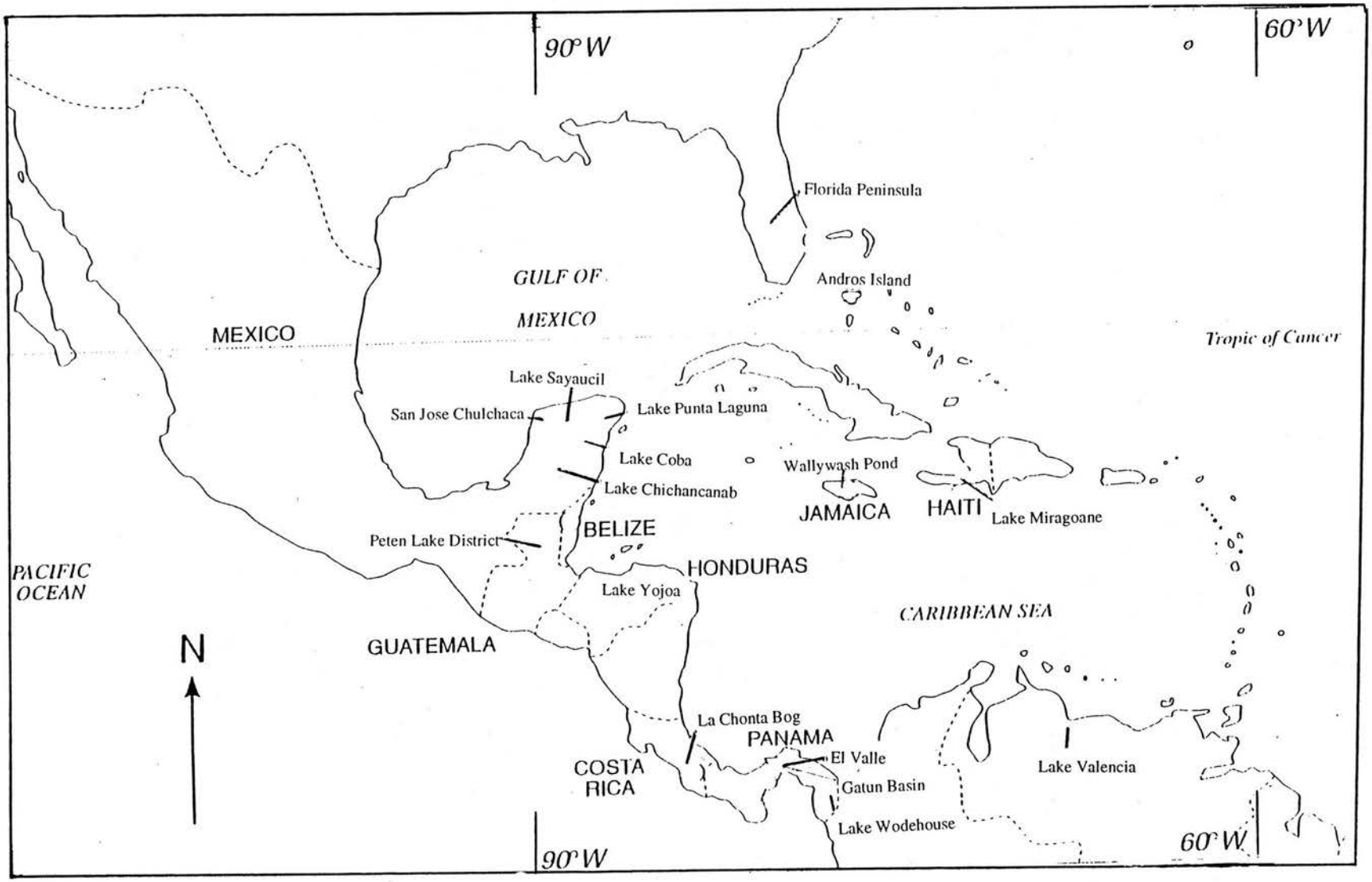


Figure 2.1 The location of climate records in the circum-Caribbean

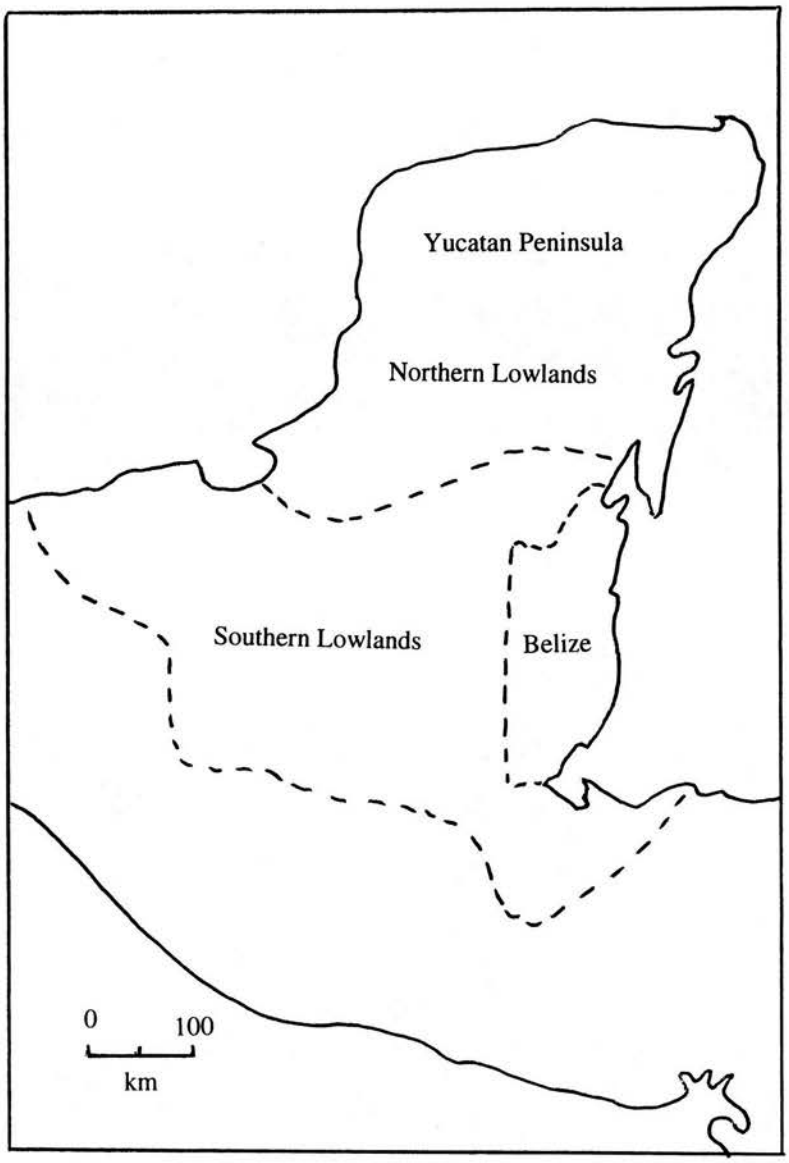


Figure 2.2 The Southern Lowlands (modified from Jones, 1991)

Chapter Three: The Maya

3.1 Introduction

Both human and physical forces shape the environment. In order to develop an understanding of the modern landscape the role of both these forces needs to be appreciated through time. This thesis aims to reconstruct the environmental changes that have affected Belize through time. An understanding of the human history of the area is therefore essential to the successful completion of this aim. The Maya are the native peoples of southern Mexico, Guatemala, Belize and Honduras having occupied this area for the last 5-6000 years. The region of interest to this investigation is the Southern Lowlands which comprises the Peten region of Guatemala stretching northwards to Tabasco and southern Campeche, Mexico; Belize; the Rio Motagua of Guatemala and a narrow portion of western Honduras (Coe, 1997) (Figure 2.2). With the exception of the Olmec and their associated groups, the Maya were the only new world high civilisation to arise and flourish within a tropical lowland forest ecosystem (Brenner, 1983). The development of the civilisation can be charted through a series of distinct periods (Coe, 1997):

Archaic	to 1800 BC
Early Preclassic	1800-1000 BC
Middle Preclassic	1000-300 BC
Late Preclassic	300 BC- AD 250
Early Classic	AD 250-600 (this includes the Hiatus: AD 534-593)
Late Classic	AD 600-800
Terminal Classic	AD 800-925
Early Post Classic	AD 925-1200
Late Post Classic	AD 1200-c.1530

People have been fascinated by the Maya ever since Stephens and Catherwood rediscovered the sites of Central America in 1839. From this time on, there have been numerous excavations of Mayan sites. By the Late Preclassic, regional societies

of thousands of people had developed, in the Early Classic this had risen to tens of thousands and in the Late Classic to hundreds of thousands. The total population in the Maya Lowlands is believed to have peaked at between 9 and 14 million (Adams, 1991). Tainter (1988) estimates a population density in the Southern Lowlands of c. 200 people per km^2. This would have made the Lowlands one of the most densely populated areas of the pre-industrial world.

Maya settlements have been regarded traditionally as religious centres but some sites were more inclined to this purpose than others (e.g. Copan, Honduras). The Maya economy has been described as elite controlled and ceremonial on the one hand and redistributive and dependent on markets/trade on the other. The society was patrilineal, patrilocal and patriarchal. Maya subsistence was both extensive and intensive (Pyburn *et al.*, 1998). All these seemingly contradictory statements are correct as they can be applied to different areas at distinct times. The analysis of regions cannot, therefore, be undertaken using simple rules as these will not capture the essence of the society and how it developed through time with different power struggles and different centres of influence.

One of the key research issues concerning the Maya is how their Classic civilisation came to an end in approximately AD 850. Popular literature describes this period as a collapse, which implies a rapid and catastrophic end. With the shift in archaeological focus in the 1950s away from ceremonial architecture to settlement surveys, the magnitude of the population decline at the time of the collapse was more fully appreciated (Willey, 1982). During the six centuries of the Mayan florescence the Maya created a society which was characterised by elaborate art and architectural styles, complex calendrical and hieroglyphic systems, long distance trade networks and spectacular ceremonial centres (Healy *et al.*, 1983). Today hundreds of these sites lie as ruins across Guatemala, Belize and the Yucatan Peninsula highlighting both the wide distribution of the culture and their dramatic collapse. There are three sets of literature which can be investigated: anthropological, archaeological and more recently the palaeoclimate literature, to gain ideas about the collapse. One of the

most interesting aspects of Maya research is the development of the theories concerning the collapse and how ideas have changed through time.

The collapse of the Mayan civilisation has been one of the most persistent research issues to have occupied archaeologists and anthropologists alike. The collapse was preceded by a period known as the hiatus (AD 534-593) which was a time of severe cultural decline. The collapse and its implications will be explored in more detail in section 3.5. The collapse is unlikely to have uniformly affected the whole of the Southern Lowlands at one time. Gill (1994) estimated that it actually extended from AD 760-910.

The abandonment of the practice of erecting monuments bearing long count dates (the calendrical system devised by the Maya) was traditionally taken as the evidence for the dramatic collapse of the Maya. However, the withdrawal of this process was only one symptom of a widespread process of change that operated over several centuries. No single event or process was responsible for all the changes seen at the close of the Classic period and the sequence of contributing events varied from region to region and even site to site (Adams, 1973; Sharer, 1994).

The traditional view concerning the 9th Century was that this was a period where the Mayan people experienced a time of dramatic upheaval that resulted in the collapse of the society. Through the increasing amount of work that is being carried out at Mayan sites, it has become apparent that different areas coped with the changes that occurred at this time in very different ways. One certainty is that Classic period culture did undergo a major transformation in the 9th Century AD. Tikal and similar sites appear to have experienced a true collapse whereby people left these high-density urban areas to join or create low density settlements that were near water-bodies. The fact that the Mayan civilisation collapsed in its entirety is a myth that is commonly retold in the general literature and by the media. Key sites that did not collapse were Lamanai and the coastal sites of Belize (Graham, 2001).

Adams (1973) defines the collapse in terms of the failure of the elite combined with the abandonment of palaces, cessation of temple and stelae construction and the diminishing use of calendrical and writing systems. This all occurred during a time of rapid depopulation of the countryside and ceremonial centres. The collapse of the Classic Mayan civilisation began in c. AD 760 and continued for the next 80/100 years with hundreds of major sites being abandoned over at least half the lowlands area and in the remaining half, the site occupation and construction declined markedly. The pattern of events for the Southern Lowlands is clear but in the Northern Lowlands the collapse is not thought to have been as severe (although much less research has been undertaken in this area). The Mayan civilisation was a substantial achievement especially considering that the Lowlands are not optimal lands for agricultural production. One of the main premises behind this thesis is the investigation of the climatic changes that occurred in the Holocene and more specifically the enhanced understanding of the late Holocene dry period. This arid period coincided with the collapse and it has been postulated that these two events are connected (e.g. Curtis *et al.*, 1996). It is important to go through the changing schools of thought regarding magnitude, extent and causal mechanisms behind the collapse as it provides a context for the presently accepted ideas.

The aim of this chapter is to develop an understanding of the human forces that have shaped the landscapes of Belize. This will be achieved by developing an understanding of the Mayan society and how it both utilised and impacted upon its environment. This, combined with a knowledge of the general trends in society (achieved through the study of the main Mayan sites in north Belize) will enable an appreciation of both the role and importance of humans in the history of Belize.

3.2 Rural activities and environmental impact

The Maya exploited a wide range of agricultural techniques to deal with the vast array of physical environments in which they were based. The original view of the Mayan civilisation was that they were supported by shifting agriculture, had only a limited population and lacked true urban centres (Adams, 1991). Research since the

late 1960s has completely disproved this viewpoint and it is now known that although the Maya began by practising shifting agriculture, because of population pressure in the Late Preclassic, they began to employ more intensive techniques. It was this transition that was associated with the development of cities.

The Mayan society at its inception was based on a hunter-gatherer system along the Caribbean coast. Settled village life is thought to have begun around 4200-3300BC (Sharer, 1994). The first type of agriculture that was employed was extensive i.e. large areas of land were utilised but the yields produced were low. The oldest method of intensive agriculture that has been found is in the form of household gardens. This system was based on a plot of land adjacent to the house and the soil fertility was maintained by the addition of household rubbish. The key intensive systems that were employed at the height of the Mayan success were terraces and raised fields which enabled much more land to be used productively. These are rarely found today. Investigations have shown that maize was the staple crop from Preclassic to Historic times for the Maya, although consumption appears to be highly influenced by cultural change (White *et al.*, 1993).

The Maya were constantly altering their environment resulting in the creation of a highly productive setting. During the initial colonisation period of the Maya (up to c 1000 BC) the coastal zone was the only main area that could support a settled society. With rising populations, people gradually moved inland following rivers and settling in swamp margins. These depressions ('bajos') often held water throughout the dry season and therefore could be used for agriculture. Shifting agriculture was not found to be an efficient way of utilising land because after three years of cultivation, land had to be lain to fallow for four to eight years to ensure continuing fertility (Adams, 1991). Maize was always a staple agricultural crop but frequently polyculture was undertaken which used a number of tropical domesticates (Scarborough, 1998). There is also evidence for a wide range of root crops, tended tree crops and cotton (Hammond and Miksicek, 1981). The strategy employed is vital to the success of the system because for example crop losses occur due to weeds, insect infestations and plant diseases. These become much more significant

the longer a field is under successive cultivation. This is especially severe if only one crop is planted. Farmers found that they could counteract drops in productivity by cultivating more land, but because of the increased labour input which was needed per hectare with such a scheme, there was a finite amount of land that could be cultivated at one time. Successful agriculture therefore mimicked nature with a variety of crops being planted at the same time.

Evidence of permanent settlement is not found until the Late Preclassic period with the appearance of food storage pits. By the Late Preclassic sizeable populations were established throughout the Lowlands, all of which demonstrated localised techniques in dealing with the seasonal climate and the wide variety of ecosystems (Scarborough, 1998). The role and types of agriculture that were undertaken within the Maya communities is very important to determine in order to develop a clear idea of how the various societies operated through time in Belize. It was the discovery of rectangular canal patterns on the margins of riverine wetlands that led to the suggestion that the Maya may have developed intensive agricultural techniques in the Classic period. The patterns observed are thought to represent intensive hydraulic systems to improve crop-soil-water relations and to extend cropping into the dry season (Turner and Harrision, 1983).

Within wetland cultivation, drainage channels, raised fields and water control devices were employed. These required a great deal of labour, planning and materials. It is thought that every major swamp, watercourse and lake edge in the Southern Lowlands was exploited for agriculture by the end of the Classic period (Adams, 1991). Controversy still exists however about the nature, chronology and extent of the modifications (Adams *et al.*, 1981; Turner and Harrison 1983; Pope and Dahlin, 1989; Pohl, 1990 and Culbert, 1991). A raised field is an agricultural feature created by transferring earth to raise an area above the natural terrain. An example of where they were found is Pulltrouser Swamp and Barber Creek near Lamanai (Turner and Harrison, 1981). Raised fields and associated canals provided dry, cultivable land in areas otherwise subject to inundation. Terracing allowed directed drainage on both steep and shallow hillsides, trapped silt and created fertile areas

(Tainter, 1988). Water channelling and storage involved a variety of techniques (not all of which related to agriculture) but were all labour intensive.

The Lowlands as a whole are deficient in surface water, especially during the dry season therefore canals, dams, reservoirs and small wells were built. Caracol (south Belize) had man made reservoirs, one of which even holds water in the dry season today. Due to the thin soils in this area terraces were also employed. The terracing systems at this site showed a high degree of planning. The upper elevations of the slope were untouched and lacked terracing. This treed zone may have acted as a biological reservoir and a source of wood, food and medicinal plants. The vegetation cover would have intercepted some of the rainfall which would have fallen on the area, reducing the amount flowing down the slopes. The water that did flow through the system would have picked up nutrients and brought them to the lower slopes (Healy *et al.*, 1983). Evidence from the 'Programme for Belize' region in north Belize suggests that terraces were constructed through the modification of natural contours with the new features averaging 10 metres in width and 1.5 metres high (Walling, 1995). The purpose of these structures appears to have been to amend slightly degraded land rather than improve the worst areas.

Dry season water supplies appear to have been crucial in the development of complex societies in the Lowlands (Adams and Valdez, 1995). It has been suggested that water control was the means by which the initial Mayan leaders were able to shift religious power to political power. Northern Belize has more reliable sources of groundwater than the central Peten region and therefore there would have been less opportunity to monopolise resources. This may be part of the reason why large political centres did not develop in lowland Belize. Communities that were larger than villages had to have reliable storage facilities that could provide the community with enough water to last for about 100 days without rain in the dry season. In conjunction with this further water management strategies would have had to control erosion and flooding during the heavy downpours in the wet season. Such features have been noted in Guijarral which is located in Programme for Belize land. This settlement is located on high land surrounded by a high frequency of reservoirs. The

reservoirs were designed to allow water to escape gradually in times of very wet conditions by having one side higher than the other. The lower lip of the reservoir in Guijarral consistently faces downslope and away from the settlement. The terrace systems below would have slowed the movement of water, preventing excess soil loss (Adams and Valdez, 1995). This intrinsic understanding of water management highlights the central place that this resource had in Mayan society.

In the Late Preclassic water management was a 'concave' micro-watershed adaptation i.e. sites were low lying and relied upon natural slope runoff (i.e. Cerros, north Belize). In the Classic period sites like La Milpa (north-west Belize) practised 'convex' micro-watershed adaptations. This allowed communities to move away from the traditional areas in which they had been located. Sites were positioned on natural hills so that the quarried surface for construction fill and the resultant reservoir and rainwater catchment surfaces could best be utilised. This system allowed for much greater control but also shows the great awareness of the Maya about the best management of their surroundings (Scarborough *et al.*, 1995). The development of these extensive water management systems implies that economic and political power was being centralised into these large cities.

3.3 The sites investigated in this study: Introduction

In order to gain a real appreciation of the human history of Belize it is important that knowledge of the main archaeological sites is unravelled. This will provide two key sets of information:

1. The primary development areas of Belize; the shifts in political power; agricultural zones and the general affects of the postulated collapse around AD 850.
2. A context for the two key areas under consideration in this investigation (New River Lagoon and Honey Camp Lagoon).

The aim of the following section is to provide a history of the New River Lagoon and Honey Camp Lagoon through the work that has been carried out by archaeologists.

This is essential in order to unravel the records of environmental change, that have been produced in this investigation (see Chapters 6,7 and 8). The history of human occupation and activity will provide a context and a relative chronology for the lake sediment sequences. Knowledge of the sites can also be related to the other centres in the country enabling an assessment of the importance and role of the New River Lagoon and Honey Camp Lagoon. These sites are shown in detail on Figures 3.1 and 3.4.

3.3.1 Lamanai

The first published investigation of this site was by Pendergast and others in 1974 (Pendergast, 1975). The first documented visit to the site was, however, by Thomas Gann in 1917 (Gann, 1928). Lamanai is unique in Belize because of its unbroken span of occupation which lasted for 2000 years. The site name in Mayan means drowned insect or crocodile. The site had an extensive and well-developed population by 300 BC and it was an extremely important Preclassic centre (Pendergast, 1981). The founding of the site is thought to have been as early as 1500 BC. The key part of its historical development was the fact that it survived the Classic collapse (Pendergast, 1981). The post-collapse period shows a transformation of social organisation and technology without a change in the local population (Masson, 1997).

An area of 6Km^2 has been studied around the main site. The main structures form a compact zone in the centre, outside of which the scale and density of buildings rapidly diminish (Loten, 1985). Lamanai does not have a standard settlement pattern which consists of more than one ceremonial precinct plaza. This is due to the proximity of the lagoon, which has lead to a strip-like development along the shore (Pendergast, 1981). A shift in the affiliations of the site has been noted in the architecture and ceramics. In the Preclassic and Early Classic the links appear to have been with the Peten region of Guatemala. This weakened during the Late Classic as the Peten reached its cultural peak. By the Postclassic, Lamanai was linked to the northern Yucatan region (Loten, 1985). It has also been noted that there

are architectural links between Lamanai and Cerros (which is located at the mouth of the New River) (Pendergast, 1981). Lamanai like many other Late Classic centres was under very strict elite control (Pendergast, 1981).

Information on population levels through the site's history is sparse. It is believed that the peak of the population was in the Preclassic and into the Early Classic and this may have been as high as 10,000 (Lambert *et al.*, 1984). Ridged field systems have been found 32 km northeast of the site and these are thought to have been utilised by the people of Lamanai, suggesting that they undertook intensive agriculture. Evidence has also been found for the use of maize as an agricultural staple (Lambert and Arnason, 1978). By AD 1637 the population of the site was 72 (Jones, 1989).

An indication of changing population levels can be gained from the time periods in which the major temples were built (Figures 3.1 and 3.2):

1. N10-43: This is the largest Preclassic structure in the Maya area and to build it would have required a considerable workforce that was under the control of a well-maintained hierarchy of elite.
2. P9-2: Late Preclassic structure.
3. P8-12: This structure was both built and modified in the late Preclassic
4. N10-9: This building was completed by the early Classic, modified both in the late Classic and the early/mid Postclasssic.
5. N9-56: This was constructed at the end of the early Classic.
6. N10-7: This is a Classic structure that was heavily modified in the mid-Postclassic.
7. The Ottawa Complex: Classic period construction but during the late 9th or early 10th Century it was massively modified (Pendergast, 1981; Loten, 1985; Graham, 2001).

It appears as if there were two key phases to the construction activities in Lamanai. The major monument building phases occurred in the Preclassic and the Classic. The late Classic and Postclassic appear to have been periods of building modification

rather than construction. Both these phases would have had different impacts on the environment.

The building of N10-43 in the Preclassic not only required a large workforce and an organised elite it would have also required trained architects, designers and astronomers (for temple location) as well as reliable food supply mechanisms either through an agricultural workforce or through trade networks. The construction of this building is thought to have been completed by 100 BC.

The key period in Mayan history, between AD 850-925, was vibrant in Lamanai. No evidence has been found in the ceramics or architecture for a break at the beginning or the end of the Terminal Classic. This community survived the collapse and continued throughout the Post Classic while neighbouring sites were gradually being deserted. According to Pendergast (1987) there are three reasons, which may have contributed to this. Firstly, Lamanai is situated at the edge of a large lake meaning the inhabitants would have had a richer and more varied diet than was available at land locked sites. Secondly, the New River Lagoon provided the inhabitants with an open means of communication with the northern Maya area and other parts of Mesoamerica which would have enabled trade routes to continue. Thirdly, undetectable factors such as the strength and personality of the community's leaders. These would have provided a force of stability at a time of crisis. There is archaeological evidence in the Postclassic for mass production of pots using moulds. This is clear evidence that Lamanai was part of a trade network during this time frame. There is also evidence that copper was being imported from AD 1200 and by AD 1400 it was being made on site (E.Graham, pers.com. 2001).

The site, at the time of the Spanish arrival in 1540, was concentrated in the southern half of the area with a northern satellite town (Pendergast, 1987). The transition to the south is thought to have occurred in the 11th Century (Pendergast, 1985). The settlement was directly adjacent to the lagoon edge, in an area that was formerly a ceremonial zone in Classic times. There is much evidence throughout the site of a move from a ceremonial to residential use of buildings and zones during the 11th

Century (Pendergast, 1985). The important point to note is, however, a continual use of the lagoon edge.

The first church was built at the site in AD 1567 and was a Mayan building adapted for Christian use. The second, built near the end of the 16th Century, was European in style. This latter church was much more impressive and may signify a strengthening of the Spanish hold over the area (Pendergast, 1984). The church at Lamanai first appeared on the church list of AD 1582 (Roys, 1957) and the site was first visited by Fathers Bartolome de Fuensalida and Juan de Orbita in AD 1618 (Pendergast, 1981). In AD 1640 the Christianised Maya desecrated the church and allied themselves with the citizens of Tipu in central Belize. Incidentally, Tipu had exactly the same style church built in the late 16th Century (Pendergast *et al.*, 1993). Lamanai at this time was not, however, entirely abandoned (Loten, 1985) with the few inhabitants left still identifying the church area as a sacred space and undertaking some Christian practices (Pendergast *et al.*, 1993).

Lamanai appears on European maps from 1622 suggesting that its Spanish rulers regarded the site as important. This is not surprising due to its strategic position at the headwaters of the New River Lagoon, which is the principal water route into the southern interior of the country. In maps dating from the late 19th to early 20th Century, Lamanai is not recorded. Indian Church, the modern day settlement in this area, is marked on most of these suggesting that it was this site and not the original territory that was being utilised during this time period.

In the 19th Century a sugar mill was in place near Lamanai. The fields appear to have been concentrated in the area south of the main ancient centre and west of the church. This was closed down in the 1870s (Pendergast, 1975). There is also evidence of 19th Century British buildings and activity along the shoreline (Pendergast, 1986).

3.3.2 Hillbank

There are thought to have been 15 Spanish colonial towns in Belize. One of these is Colmotz, which is believed to have been located at the modern day site of Hillbank (Pendergast, *et al.*, 1993) (Figure 1.1). The terrain of the west bank of New River Lagoon is attractive for settlement, especially in comparison with the low-lying swamps on the east side (Figure 3.3). Its elevation protects against flooding and provides a good view of the Lagoon which may have been useful in terms of defence. These same benefits would also have been felt in Lamanai. Due to the extensive modification of this site in modern times any archaeological information which was present has been destroyed. The small amount that has been found suggests that the site was existence during the Terminal Prehistoric or early Spanish period (Pendergast *et al.*, 1993).

Hillbank was the site of extensive logging operations in the 19th and 20th Centuries. The site is noted as early as 1867 and on the maps dating from 1938-1952 the New River Lagoon is named Hillbank Lagoon. It is still referred to as such in Wright *et al.* (1959) even though logging is thought to have stopped in this area some time before 1949. This suggests that this was an area of significance. The name 'bank' in Belize predominates in northern river sites and it relates to those areas exploited for logwood transport (Duncan, 1966). The Lagoon is the only source of permanent water in this area.

3.3.3 Honey Camp Lagoon

The original name for this Lagoon was Laguna de On or Lake of the Alligator Pear. Honey Camp was an experimental station for the intensive study of the Sapote tree and the logging camp associated with this was situated to the southwest of the lagoon on a high bank (Gann, 1928). Although the Lagoon is self-contained, the adjacent Doubloon Bank and Button Lagoons did connect to the Caribbean Sea through Freshwater Creek which is now silted up (Masson, 1993) (Figure 3.4). This is thought to have been a route to the Caribbean Sea during Classic and Postclassic

times (Masson, unpub). A location near this route would have been of great strategic importance. There are two small islands at the south end of the Lagoon which have two metre high platforms made out of lagoon sediment upon which Postclassic artefacts have been found. The western of the two islands appears to have been connected to the shore by a bridge of sand (Masson, 1993).

Two key Mayan communities inhabited this site. The first population was located on the shore during the Terminal Classic/ Early Postclassic and the island population was founded here during the Postclassic (from AD 1100) (Masson, 1995). It is not known whether this latter population was a replacement or a displacement of the original shore community (Masson, 1996). The origin of the Honey Camp community is a critical issue in trying to resolve the extent of the collapse in this area. There are two scenarios which could have occurred:

1. The island population could have been migrants from a different area with the natives dying *in situ.*
2. The native population could have migrated to Lamanai (the nearest site that was populated during this period) or indeed taken refuge on the island suggesting that the collapse was a time of downscaling and consolidation (Masson, 1993).

This site, like its much more powerful neighbour Lamanai, occupied a strategic position in the Postclassic between the Chichen Itza, Mayapan and Peten regions (Masson, 1995). It appears to be a general trend in north Belize that settlement patterns in the Postclassic moved towards defensible island or shoreline locations. Both Honey Camp and Lamanai fit into this category (Masson, 1997). Although current evidence points to two distinct island and shore communities in this area, it has been discovered that during the Early Postclassic ceramics were made using less intensive labour techniques, and thus it is possible that these may have been overlooked in archaeological investigations. This would mean that any Postclassic population on the shore may be severely underrepresented in the archaeological record (Masson, 1995).

Archaeological evidence from the main island suggests intensive and elaborate landscape modification was employed to improve the island's contours to make it more suitable for habitation. This includes the development of a dock (Masson, 1996). This has given a fortified appearance to the island. It is unsure where the fill for all these structures came from, whether from the island itself or the lagoon shore. If the latter is the case then this would have created significant disturbance (Masson, 1996).

During the Classic period large animals are scarce or absent from the forests in this area (Scott, 1980; 1982) and pollen records show extensive deforestation (Rice, 1986). Agricultural production appears to have been the mainstay of both communities in Honey Camp Lagoon (Masson, 1993). Evidence has been found for the cultivation of corn, beans, squash, cotton and cacao (Masson, 1999). The period from AD 1000 to 1400 appears to have been a time of growth and development without disruption. From AD 1250 onwards there appears to have been a change in the community structure with a greater emphasis being placed on ritual and community leadership (Masson, 2000a). From evidence of skeletal remains it is apparent that forest dwelling animals were present in this area in the 12^{th}-14^{th} century suggesting improved ecological conditions during this timeframe as compared to the Classic period (Masson, 1996).

3.3.4 Summary

Although the level of knowledge concerning these sites is not as great as some of the major sites of the Southern Lowlands, the information presented provides a valuable context within which results concerning environmental change can be placed. The two sites appear to have responded in different ways to the AD 850 collapse period. Lamanai appears to have been stronger in terms of resources, leadership and connections, which may have contributed to its ability to survive. Both sites record different phases to their histories demonstrating that the impact/influence of the Maya was not consistent through time or space. Both indicate the importance of location i.e. use of lagoon and island and show clear human impact both in Mayan

and colonial times. With the knowledge gained from the archaeology it will enable a much greater appreciation of the palaeoenvironmental records produced from these lagoons. The differences in these sites will provide this study with a greater applicability throughout the country.

3.4 Mayan sites in northern Belize

The sites which will be discussed in this section were chosen because each site succinctly demonstrates a key feature of either Mayan society or their interaction with the environments in which they inhabited. The focus is on sites from north Belize as this is the specific area of interest to this thesis. These sites are all marked on Figure 3.5.

Cuello is a Preclassic site (Tourtellot *et al.*, 1993) and occupation is thought to have taken place at this site before major architectural construction began (Hammond and Miksicek, 1981). It is apparent that by the end of the Archaic period the environment surrounding this site had already changed as a result of human manipulation. This trend continued into the Middle Preclassic with increasing levels of open woodland and cultivated land. Hammond (1991) calculated Cuello's population dynamics. It is thought that in the early Middle Preclassic 296-370 people occupied this site. This grew to 571-711 people in the late Middle Preclassic, rising to 2200-2600 in the Late Preclassic. Cuello at this point could be regarded as a small town with a clear social structure, rather than a village. The site reached its peak in the Early Classic with a population of 3400 people, falling to 1100 people by the Late Classic. It is therefore in the Late Preclassic that this site experienced the beginning of a rapid and massive rise in population, site size and density. It is believed that intensive agricultural techniques were also developed because evidence for channelled and raised fields has been found (Hammond and Miksicek, 1981). The animal bone remains at Cuello contain a high proportion of mammals suggesting that they were a food source for the population. This site demonstrates the typical pattern of both population growth and provides evidence as to how the Maya manipulated their environment.

Nohmul was a major Maya centre which was founded in the Early Preclassic. It has one of the longest occupation sequences in the region. During a time span of two millennia it was a successful community in terms of population size and architectural development. This site had a bimodal peak of population and monumental construction in the Late Preclassic and the Late Classic (Hammond, 1985). There was also a final burst of activity during the Terminal Classic/ Early Postclassic in the 10^{th} Century. During the bulk of the Classic period, when most of the Maya centres were flourishing, Nohmul was abandoned. Channelled and raised fields are found dating to AD 700-1000 which coincides with the second florescence of Nohmul. This event was due to the reoccupation of the site by people from a non-local architectural tradition. The same pattern is demonstrated in Seibal, Altun Ha and Colha and has been attributed to the southward movement of the Itza people. This population was located at the site of Chichen Itza in the Yucatan Peninsula. The group which reached Nohmul were numerous and organised enough to build a series of public buildings inside the plaza of the Terminal Preclassic and the Early Classic ceremonial centre (Hammond, 1985). Hammond *et al.* (1987) regard Nohmul as a major population centre at a time when many other sites were failing. It perhaps served as a regional centre of government that flourished briefly before the collapse.

Pulltrouser Swamp forms the eastern boundary of the Nohmul settlement and the earliest cultivation of fields in this area has been dated to the middle Late Preclassic. It has been estimated that only 20% of the population could have been supported by the fulltime cultivation of all the known field complexes around Nohmul (assuming that the staple crop was maize). It is, however, possible that some of the field systems could have been used for the growth of cacao for trade (Turner and Harrison, 1983). Evidence from Nohmul and Pulltrouser Swamp provide further evidence on the type and scale of agricultural activities conducted in Belize. The site demonstrates an alternative history of settlement to that found in Cuello.

Colha is a Middle Preclassic to Post Classic site located on the edge of Cobweb Swamp (Jones, 1991). It was important as a production rather than ceremonial centre. There is evidence that occupation at this site goes back to Archaic or even

Pre Ceramic times, but there are no radiocarbon dates to substantiate this claim (Jones, 1991). The earliest permanent house structure dates back to 700 BC and lithics/ceramics of Middle Preclassic age are abundant suggesting that the site was permanently occupied by this time. Jacob (1995) concludes that the reticulated field features discovered along the margin of Cobweb Swamp represent human modification of natural channels and islands for agriculture. This is thought to have begun as early as the Middle Preclassic (800 BC). Disturbance of this site is however noted from 2500 BC onwards, involving large-scale forest clearance with maize and manioc cultivation. This is based on pollen evidence (Hester *et al.*, 1981). The Late Preclassic shows a dramatic increase in population, which was matched by an intensification of forest clearance and agriculture. At this time at least 31 of the 89 known workshops were active. This signifies a huge production of tools, as each workshop would have been capable of producing 75,000 a year. Simplified tools were also produced which suggests that a mass production market was being catered for (Hammond, 1982). Tools produced by Colha in the Late Preclassic have been found as far away as Moho Cay (Hammond, 1982). The Late Classic (AD 600-850) saw a second florescence of Colha as an industrial centre (Hammond, 1982). Colha, however, no longer had the monopoly over the market, due to sites such as Altun Ha entering into tool production (Hammond, 1982). The cultural links between Colha and northern Belize were very strong in the Late Preclassic. These had weakened by the Late Classic as Colha became increasingly under the influence of Altun Ha to the south (Hammond, 1982).

The final occupation of Colha appears to have come to a dramatic end with the execution of the ruling elite by the Itza invaders from the north. The archaeological evidence to support the northern origin of the new lords of Colha is consistent with other sites from the region (i.e. Nohmul and Altun Ha). The site of Colha was therefore a major industrial site of the Late Preclassic proving that the Preclassic Mayan civilisation was a firmly layered and highly organised hierarchy. By AD 1350 the site was abandoned (Jones, 1991). The site of Colha demonstrates the wide range of activities which the Maya undertook and consequently the wide range of impacts they would have had on their environment.

At **Altun Ha** there is evidence for contact with Central Mexico as early as the 2nd Century AD. At this time the population of Altun Ha increased by 50% and the area occupied by the site increased by 32% (Pendergast, 1971). Altun Ha was not a likely choice to be influenced by Teotihuacan because it is located near the Caribbean coast of Belize, and it is much further away from Teotihuacan, Central Mexico than other sites in Peten. This contact marks the beginning of a two-way flow of ideas between the Southern Lowlands and Mexico (Pendergast, 1971).

The most significant part of Altun Ha's history was after its decline at the end of the Classic period. It is not thought that the site was completely devoid of population at this time and there is evidence that there might have been trade between a remnant population and Lamanai between the 12-14th century. Altun Ha was revived in the 15-16th Century and this population represents a break with the past and was not related to the previous group that inhabited this site. It is thought that the occupiers were pilgrims. Although Altun Ha was not a major centre of population it lay on important communication routes and its history emphasises the importance of the coastal zone for the Maya (Hammond, 1981). The influence of this site has been noted in a number of surrounding centres of population. This site provides an interesting point of comparison with Lamanai as it was believed to be of similar importance but it had quite a different history.

A large tract of land in the northwest of Belize is owned by the conservation charity 'Programme for Belize'. From 1992-1994 the archaeology of this area was intensively surveyed (Adams and Valdez, 1993; Adams, 1994; Adams and Valdez, 1995). The major site in this area is **La Milpa**, but there are 18 other smaller sites. The larger sites are located on high ground surrounded by swamp with smaller sites being found on the periphery about 500 to 1000 metres from the swamp edges. These smaller sites played an integral role in the administration of intensive agricultural activities (Robichaux, 1995). This pattern is also seen at Tikal, Guatemala. The occupation of the area began around 900 BC with a few scattered pioneer families. The hiatus was a very clear event in this area and lasted for 120 years. The peak in

population levels occurred during the Late Classic. In more recent times this area was heavily utilised for logging purposes (Barnhart and Hargrove, 1995).

La Milpa was a major Late Classic Lowland Maya site located mid way between Rio Azul (Guatemala) and Lamanai (Tourtellot *et al.*, 1993). The ceramics which have been found, link La Milpa to sites in the Peten Lake District, Guatemala rather than to Nohmul or Lamanai. It appears that La Milpa was the northeastern limit of Peten regional culture. The site was a major regional power as early as the Late Preclassic and throughout the Classic. At its peak it is thought to have been the same size as Lamanai (Guderjan, 1991). It appears to have operated as a pilgrimage site in the Postclassic (Hammond and Bobo, 1993).

The coast was a very important location for the Maya in terms of communication , trade and resources. **Cerros** is one of the most important coastal sites as was the island site of Ambergris Caye. Within the archaeology literature Cerros is regarded as a good example of a site whose major occupation was confined to the Late Preclassic. There are traces of earlier initial settlement and, after a hiatus in the Classic, a substantial Postclassic occupation. This pattern is repeated in Santa Rita, located across the bay (Hammond, 1981). The key feature of Cerros was its location at or near the mouth of the New River on Chetumal Bay, which would have made it a coastal lookout station. Cerros has major public architecture dating to the Late Preclassic period. It appears that during this time the community underwent a dramatic transformation from an egalitarian fishing and trading community to a cosmopolitan, political and hierarchical society (Freidel, 1986). There appears to have been a shift towards the coast in the settlements between the Middle and Late Preclassic accounting for Cerros' development as a major site at this time. The centre of this site is much larger than the one at Colha, suggesting that it was a significant trade centre, but, this is very hard to establish from archaeological data alone (Freidel, 1986).

The relationship of Cerros to the coast in Late Preclassic times differed from the present situation. The shore of Corozal Bay has eroded through time cutting into the

nucleated village remains. The implication is that the New River mouth was closer to the site at the time of occupation, than its present position some 3.5Km to the south (Pohl, 1985). Friedel (1986) notes great similarities between Cerros and sites in Central Peten which suggests that there must have been communications between these areas.

The occupants of Cerros would have had access to a variety of aquatic habitats. Modern residents of the area exploit streams, seasonally flooded savannas, fresh to brackish mangrove-lined lagoons and the sea. The terrestrial environment includes well-drained areas in which the climax vegetation is a deciduous tropical forest. The amount of vegetation that was present at the time of occupation would have depended on the extent of agricultural land clearing. Guderjan and Garber (1995) conclude that large-scale maritime trade was a Classic and Postclassic phenomenon with Late Preclassic Cerros being an interregional port (Garber, 1989) implying that trade may have been an important mechanism in the development of the Mayan civilisation. Classic period trade provided goods which reinforced the authority of the elite, but, gradually by the end of the Classic period these goods found their way to household level, which would have contributed to the disruption of elite control of society (Guderjan and Garber, 1995).

Ambergris Caye was also important in terms of trade networks in Belize (Guderjan and Garber, 1995) (Figure 1.1). The occupation of Ambergris Caye began during the Late Preclassic while Cerros flourished as a trade centre. The Caye was permanently occupied by the Early Classic and formal architecture appeared by AD 600. Although the site was intensively occupied around the coast this did not extend to the interior of the island (Guderjan and Garber, 1995). Communities were centred either on natural or artificial harbours. There is evidence for Terminal Classic trade with the Yucatan Peninsula, Campeche, south and north Belize. By the end of the Terminal Classic (AD 1000), however, all the towns with the exception of Marco Gonzalez were abandoned. (Pendergast, 1990).

The site of **Marco Gonzalez** on Ambergris Caye has been found to have had great links with Lamanai from AD 1100-1300 (Graham and Pendergast, 1989). This may account for its ability to survive when nearby sites were in decline. It is thought that the New River would have served as the principal means of communication between the two sites. The amount of 'Lamanai inspired' pottery in Marco Gonzalez in the Postclassic suggests that this was the site of a pottery works. The tie between Lamanai and Marco Gonzalez does not appear to have extended to the intervening sites along the New River suggesting that these sites did not flourish during the Postclassic (Graham and Pendergast, 1989). This is surprising because the island would have been a much more fragile environment than the inland sites (Graham and Pendergast, 1989).

Albion Island had its time of maximum population in the Early Classic (Pyburn *et al.*, 1998). The occupation of this site began in the Late Preclassic and the population density has been calculated as 775 persons/km^2 (Dahlin, 1977). This is very high and the houses, which have been investigated, are small and densely clustered. This suggests that it was not extended families that resided here, but perhaps that it was the site of a large-scale commercial farming enterprise. This arrangement highlights the diversity of tactics and survival mechanisms that were put into place in the Maya Lowlands (Pyburn *et al.*, 1998). The site is thought to have been within the sphere of influence of the Peten region, with trade taking place between agricultural goods from Albion Island and urban goods from Guatemala. The farming methods employed in Albion Island show a response to environmental change through two main phases of ditching. Firstly in the Late Preclassic / Early Classic in response to rising sea level (which is also seen in the Colha records) and secondly in the Terminal Classic/Early Postclassic after water levels had stabilised/receded and the floodplain of the Rio Hondo had silted up (Pyburn *et al.*, 1998). Albion Island is the key example of organised agriculture on a wide scale. This highlights not only the enormous environmental impact that this would have had but also it portrays a clear picture of the manner in which Mayan society was conducted through elite control of the masses.

Ford and Fedick (1992) have studied the **Upper Belize River** area. This area is thought to have been one of the first to be occupied within the Lowlands as a geographical link between the Caribbean and the interior of Belize. It is also thought to have served as a corridor that allowed the population expansion at Tikal, Guatemala (Rice, 1976). The sites located in this area are examples of the rural population in Belize and illustrate not all populations were centred around large monumental sites. Excavations at **Barton Ramie** have demonstrated that this site was occupied throughout the course of prehistory including during the decline of the Classic Maya (Gifford *et al.*, 1976).

Pactibun was occupied from 900 BC to AD 900 (White *et al.*, 1993). This site was first settled as a small farming community in the Middle Preclassic and by the Late Preclassic the construction of monuments had begun suggesting that the site had attained a degree of regional prominence. Increased prosperity is noted in the Early Classic with the discovery of exotic trade goods and the production of carved monuments. Cultural development reached a peak in the Late Classic (AD 550-700) and it was during the transition from Late to Terminal Classic that the site's population reached its climax being four times higher than in the Early Classic (White *et al.*, 1993). It was during the Terminal Classic that the majority of agricultural terraces were constructed. The site was abandoned by AD 900 (Culbert, 1973).

The site of Pactibun, would have been extremely reliant on maize as it is located inland and did not have the advantage of a location near a prominent watercourse. Maize consumption reached a peak during the Late Classic and then declined after this phase of maximum population and agricultural intensification. The dietary shift to low amounts of maize just prior to site abandonment suggests that one of the reasons behind this event was over exploitation of the environment due to agricultural intensification (White *et al.*, 1993).

3.4.1 Summary

Through the investigation of the main sites in lowland Belize it has become apparent that a number of different trends have operated through the country's history. After the initial sites were set up (Cuello and Nohmul) in the Early Preclassic the main phase of site development was in the Late Preclassic. Most sites reached their peak in the Early Classic confirming the general trend of the Classic period being the most prosperous for the Maya. Nohmul and Colha are two sites which did not follow this pattern, having a bimodal pattern in the Late Preclassic and Late Classic. The timing of site abandonment varies through the country with records being confused by the movement of Itza people into the region. It has become apparent is that sites were either genuinely abandoned or in decline at the time of the collapse highlighting that this was an episode of some severity.

Through investigating the sites it has become obvious that there were an array of strategies which were employed through time, a number of different ways in which the environment of Belize was influenced by the Mayan civilisation and a number of different histories to the occupation patterns for the sites. These examples highlight both the common and divergent trends that are apparent in Belize.

3.5 The collapse

Evidence for collapse has been shown in a number, but not all of the Mayan sites in north Belize. Explanations for the collapse can be broadly divided in terms of whether the driving forces were internal; external; social or natural processes. Up until 1967 the collapse was explained in terms of internal processes only and was centred on agriculture (Morely, 1920; Sabloff and Wiley, 1967). It was believed that maize agriculture was destructive to soil resulting in the creation of man made savannas. Sanders (1962, 1963) came to the same conclusion that the overuse of the shifting cultivation system lead to agricultural and, therefore, general cultural collapse. Ricketson and Ricketson (1937) developed early ideas on soil exhaustion. They found evidence that present day swamps were once shallow lakes which have

been filled up with eroded soil from agriculture. This suggested to them that the agricultural system, which was being operated, was not a sustainable one. Further studies have since challenged these ideas e.g. Cowgill (1961) showed that the shifting cultivation system is actually highly adaptive and efficient in specific tropical forest areas. These theories all assume that maize was the main crop within a swidden agriculture system in a similar manner to modern Mayan agriculture systems.

Many of the ideas surrounding the collapse seem to question why indeed the Mayan civilisation evolved in what appears to have been a very unsustainable environment. Meggers (1954) developed the idea that the Maya lowland jungles by their very nature place a limit on cultural development, especially through agricultural constraints. She believed that the civilisation must therefore have had its origins elsewhere and hence why it collapsed. Coe (1957) refuted this theory due to evidence of *in situ* development of the Mayan people. The theory of Mayan development instigated by Meggers (1954) follows the concept of environmental determinism i.e. that the agricultural potential of an area limits the level of cultural development that can take place. The Mayans were not the only society to evolve in a harsh environment for example the Chiripa (1500-200 BC) and Tiwanaku cultures (400 BC to AD 1100) developed in very hostile environments in the Bolivian-Peruvian Altiplano. These examples defy environmental determinism (Brenner *et al.*, 2001).

Thompson (1954,1966) took the primary cause of the collapse away from agricultural failure. He believed that it three main events triggered violent internal dissension which destroyed the social system:

1. The presence of economic motivations for peasant revolt due to an increase in onerous tribute burdens.
2. The introduction of central Mexican mercenaries for the purposes of social control.
3. Moral decay resulting from the associated and introduced ideological shifts.

Altschuler (1958); Rathje (1971) and Adams (1973) all developed this idea that social structure theories should be included as part of multi factor explanations. The need for households to obtain their basic needs creates a bridge between ecology and socio-political organisation. The key problem with these social theories is that they do not account for the depopulation, which occurred at the time of the collapse.

Sabloff and Wiley (1967) believed that non-Classic Mayan peoples invaded the Southern Lowlands in the 9th Century building on the invasion theories which were first postulated by Cowgill (1964). The human-nature balance in the Southern Lowlands is fragile and thus the invasion could have pushed the system above a key threshold. All evidence points to Classic level populations being very high and thus it is likely that the strain of over population would have disrupted the system allowing for an invasion to completely upset the balance. A month or two of widespread neglect of the maize fields in a crucial season could have been enough to cause famine among the large Late Classic population, prompting people to move north (Culbert, 1973). Coe (1966) believes, however, that invasion could only have had such a profound affect on the Mayan people if their society had already deteriorated markedly. As discussed in the site histories of northern Belize evidence has been found for architectural links between the sites of Chichen-Itza, Mexico and Nohmul, Belize (Chase and Chase, 1982) and Colha, Belize (Jones, 1991). This is very important evidence for the involvement of an outside force as an integral part of the collapse. These northern sites could be where resettlement of the remnants of the Classic period people occurred which goes some way to explaining the depopulation of the Southern Lowlands at this time. The site of Seibal, Guatemala also experienced invasion in the terminal part of its history but this was of a different nature implying that it was caused by different invaders to those that arrived in Belize (Sabloff and Wiley, 1967). It is thought that the invaders in Seibal were from the from the Puuc and Gulf Coast, western Yucatan Peninsula areas rather than from Chichen-Itza. This implies that there were two separate and contemporary events in the Southern Lowlands, which ultimately had the same impact.

The collapse was not the only time that the civilisation was put under enormous strain. During the latter half of the sixth century (AD 534-593) the Classic Maya of the Lowlands underwent a marked slowing down. This period is known as the hiatus and is marked by the decrease in stelae (carved sculpture) production. The hiatus was a time of cultural re-orientation dividing the Early Classic from the Late Classic (Willey, 1974, Culbert, 1991). How do the hiatus and the collapse compare? During the hiatus stelae production stopped, but, in the collapse all major architectural activities ceased. Both these point to a weakening in the central socio-political structure of the culture. Although population levels declined during the hiatus, these cannot be compared to the levels of decline seen in the collapse (Willey, 1974). Morley (1938) believed that the hiatus was a time when the major centres were devoting their energies to building up the provinces; this is, however, unlikely. The hiatus shows that although there were inherent weaknesses in the society it was also an adaptable system because the civilisation was able to thrive after the event (Willey, 1974).

Rathje (1971) developed a theory by drawing on the experiences of the hiatus. He believed that the core area of northeast Peten was lacking in the natural products that are needed to support large complex societies i.e. hard stone for grinding corn, obsidian and salt. This therefore led to the development of long distance trade. The gathering of these resources requires organisation, which must inevitably lead to the development of a hierarchical society. Rathje named the area around the core as the buffer zone and he believed that this area served an intermediate relaying role, supplying raw materials to the core in return for luxury goods. Rathje hypothesised that with increasing sophistication and the profit derived from their more favourable geographical location, the buffer zones would have usurped the trade control from the core area precipitating the downfall of its cities. This theory is backed up by the fact that some sites located in the buffer zone have stelae which date to the hiatus time period e.g. Tonina (Chiapas) and Tulum (Yucatan Peninsula). This is not true for all buffer sites though. A further complication is that core areas did thrive after the hiatus and therefore they were not totally out-competed by sites in the buffer

zone. Sharer (1973) also refutes Rathje's theory because many of the same resources are actually found in the core and buffer areas.

At the time of the collapse both buffer and core areas were affected equally. Willey (in Sharer, 1973) modified Rathje's theory by postulating that a new outer buffer zone developed from Non Classic or Mexican Maya states along the western edge of the Southern Lowlands. This would have severely diminished trade for both the buffer and core areas. (Sharer, 1973). Webb (1964, 1973) proposed that by the Late Classic other Mesoamerican societies such as those in the Yucatan were developing in much more favourable environments i.e. rich in resources, near to new land/sea trade routes and thus they continued to develop their populations and organisational complexity. The Lowland Maya were relatively isolated from these events and being unable to compete their society collapsed. The Lowland Maya society at conception was therefore very different from the society at the end.

Adams (1973) cites Spinden (1928) "there is good reason for believing that the sudden appearance of yellow fever may have had a part in the catastrophe." It is well known that yellow fever, malaria, syphilis and smallpox were principal disease factors in the biological catastrophes that overtook the native new world populations between the 16th-18th Centuries. Disease may have had an influence in the collapse, because it would have weakened the community. Such a chain of events could be set into action through malnutrition. Haviland (1967) showed that skeletal material from Tikal had the poorest levels of nutrition at the end of the Classic period. This evidence of decline spans over a 600 year time period. Cowgill and Hutchinson (1963) also found evidence for skewed sex ratios in favour of men. These results have been supported by research by Dunn (1968) who suggests that complex ecosystems such as tropical rainforests support more disease vectors than simpler environments.

Sheets (2000) looked at the relationship between environmental stress (i.e. volcanic eruptions) and the ability for a society to survive. It became apparent through this study that complex societies are less able than simple societies to evolve and adapt to

change. This can be related to the Mayan collapse because at that time the society had a complex political structure, a large investment in architecture and sedentary agriculture.

3.5.1 Summary

Many of the theories presented are a result of work which was conducted many years ago within research paradigms that are now out-moded, but, these ideas are still being drawn upon in discussions of the Maya. The most recent research acknowledges multi-factor explanations which can be manifested in different ways in different sites. Between AD 300-800 the ancient Maya developed a complex hierarchical society in an environment which is highly susceptible to degradation. Santley *et al.* (1986) believe that it is the very success of the Maya in developing within this environment which lead to their collapse. The system was locked in a downward spiral with the need to sustain progressively larger populations placing severe constraints on the food production base, which precluded further development and ultimately lead to the collapse. These have been summarised into three key reasons behind the collapse:

1. Demographic instability. The population levels in the Classic period rose to very large numbers. The question is whether it was population instability i.e. the exponential rate of growth rather than the absolute numbers that lead to the collapse.
2. Agricultural failure (i.e. farmers making rational short-term decisions that were dysfunctional on a long-term basis).
3. The absence of regional resource links (e.g. trade networks).

It has become apparent that several factors played a role in the collapse which all resulted in a weakening of the system. Overpopulation, excessive urbanisation, soil degradation and food security problems on one side with social conflicts and a disintegration of the political structure on the other (Sabloff, 1991). Evidence

suggests that the society had reached a threshold which acted as a trigger to the collapse of the whole cultural-demographic system. (Messerli *et al.* 2000).

The collapse needs to be viewed in terms of the general organisation of the Mayan civilisation and its pattern of change and decline. Subsistence patterns developed from shifting to settled agriculture; increased diversification; heavier yielding crops; dependence on imported food crops and finally to a tighter control on land use and trade. Responses to agricultural stress included a movement away from milpa/maize agriculture to intensive agriculture based on ramon, root crops and kitchen gardens. Cultivated areas began to be developed in swampy areas around sites. The creation of cities allowed more land to be used for cultivation. Ridged fields in Belize are associated with low population densities. It is thought that these were plantations that were exploited to produce food for cities in the Southern Lowlands (e.g. Tikal). Many of the new and expanded forms of agriculture were more vulnerable to climatic shifts, natural disasters, disease, pest problems and soil exhaustion. A further source of vulnerability was the dependence of these new systems on long distance trade networks. The Maya held deeply seated beliefs in the supernatural believing that the problems which the society suffered were related to the anger of the Gods. It is possible that a great deal of agricultural labour could have been redirected towards ritual that would have been counter productive. Such a fragile system would have been easy to invade. Population densities were rising; there was a decline in per capita income; increasing local specialisation in crops; heavier reliance of the core area on the periphery for basic materials and more highly organised trade. The hierarchy of the system changed from tribal all the way up to four level states (Sanders, 1973). These developments link ecological and social theory which is an important step to making a coherent theory concerning the collapse.

3.6 The relationship between the Maya and climate

One of the key aims of this thesis is to determine whether climatic changes can be isolated at the time of the collapse of the Mayan civilisation. The traditional view in the literature is that humans had more impact on the environments of the past than

climate (Cowgill, 1964; Lambert and Arnason, 1978; Rue, 1987; Vaughan *et al.*, 1985). The concept that climate could be involved in the collapse of the Mayan civilisation first appeared in the literature in Gunn and Adams (1981) and was built upon by Dahlin, (1983); Folan *et al.* (1983); Messenger (1990); Gill (1994) and Curtis *et al.* (1996). Such ideas had been directly dismissed in the past, for example:

"...the theory that marked changes in climate have had pronounced effects upon the Mayan civilisation in Yucatan...(has been)...completely discarded by many climatologists because of the absence of direct information and it is doubtful whether there is any satisfactory evidence indicating that important climatic changes have taken place in the Yucatan Peninsula subsequent to the fifth century AD..." (Page (1933) cited from Dahlin, 1983).

In order to reach a conclusion on this topic, the magnitude and extent of the climate and cultural change at the time of the collapse therefore needs to be ascertained. This can then be used to determine whether or not the history of the Mayan people is linked to wider changes in the natural world. The uncertainty lies with the establishment of direct causal factors that can be proven to have influenced the Maya through time. A key line of research that is being pursued is the idea that climatic changes occurred at that time and were involved in the collapse. What is known is that the end of the Classic period represents a key time of change in the Mayan civilisation. It has also been established that a number of different factors may have been involved in this change.

3.6.1 Documented climate change

The records highlighted in Chapter 2 demonstrate that Belize is situated in a climatically diverse area and therefore the manifestations of large-scale climate changes will be different from region to region. The record produced by Curtis *et al.* (1996) for Punta Laguns, Yucatan Peninsula is the most high resolution sequence that has been published in this area. Curtis *et al.* found that the beginning of the Classic period was marked by a shift to relatively drier conditions about 250 cal year

AD. This raises the question as to whether the Classic Maya culture evolved in response to the climatic drying or whether climate changed because of the environmental impact of the expanding Maya population i.e. forest clearance may have reduced rainfall (Lean and Warrilow, 1989). The record from Punta Laguna, Yucatan Peninsula suggests that the Maya hiatus coincided with the first major dry phase at 585 cal year AD. The next two hundred years saw the civilisation flourish during a moist interval in between two prominent droughts at 585 and 862 cal year AD. This latter event coincides with the collapse (Curtis *et al.*, 1996).

3.6.2 The relationship

How much are humans influenced by the environment in which they are situated? Is it just coincidence that times of climatic change have occurred at the same time as cultural demise or florescence? The importance of climate and weather are apparent in Mayan culture with there being much evidence that they predicted weather as part of their activities (Folan and Hyde, 1985). Amongst sites in the northern Mayan Lowlands there are many monuments to the rain god Chac demonstrating the importance of rain in this society. It also suggests that the society may have been surviving in a marginal environment. This is also demonstrated in the modern day precipitation values (Figure 1.6).

If a dry phase affected Belize it is important to determine how the environments of Belize would have changed during this phase. Lakes and river networks, which were relied upon to be part of the transport network and a source of fish, may have dried up or become impassable. Water would no longer have been available for the agricultural systems (Gunn and Adams, 1981). Classic sites were built on hills and had man-made water management systems. These would not have worked with low levels of water throughout the year and therefore the sites which had the best chances of survival were those either near water or at the base of a watershed. The effects of such changes would not have been uniform and for societies adapted to the drier conditions of the northern Yucatan it was an environment which they would have readily been able to adapt to. This therefore provides an indication as to how the

population from Chichen-Itza would have been able to invade the Southern Lowlands (Folan and Hyde, 1985).

Correlations between human society and climate have been discovered all over the world. The present day climatic regime was established in low latitudes during the mid-Holocene c. 4070-3070 BC just before the construction of the pyramids in Egypt and the emergence of several old world civilisations (Roberts, 1996). The time period between AD 900-1250 is known as the Medieval warm period and evidence for this is widespread outside Europe (Grove, 1996). This time of climate change enabled the colonisation of Greenland by the Vikings (Roberts, 1996). A general drying of Caribbean climates occurred between (3200-1500 BP) being noted in Haiti (Hodell *et al.*, 1991) and subjectively in Puerto Rico (Burney *et al.*, 1994) the main implication of this is thought to have been the delay of human colonisation in the Bahamas.

Although evidence is strong for the existence of the extremely dry period at the time of the collapse, it is very important that its geographical extent is established. This will provide an index of its severity. As discussed in Chapter 2 evidence for this period has been found throughout Central America (e.g. Horn and Sanford, 1992; Metcalfe *et al.*,1994; Metcalfe, 1995; Curtis *et al.*, 1996; Davies, 2000). The Inca of the central Peruvian Andes were affected by the AD 900 arid event (Chepstow-Lusty e*t al.*, 1996) and the breakdown of the Tiwanaku culture in the Titicaca basin coincided with the onset of a prolonged dry period which began AD 1100 (Binford *et al.*, 1997).

Climate is, however, only one of the variables which affect human societies with its influence being strongest in those areas which are marginal for agriculture. The interplay is very much dependent on the adaptability of the society involved (Grove, 1996). To assess the true implication of climate change it therefore needs to be placed within the context of the human societies which would have been directly influenced by it.

3.6.3 Summary

Through the years a great deal of information has been amassed concerning the Mayan Civilisation, however, "...further study is needed to determine the full magnitude and geographical extent of the dry period that occurred between AD 800-1000, and to explain the intraregional pattern of the collapse of the Mayan civilisation" (Hodell *et al.* 1995). This study in Belize will go towards these ideas providing a valuable extension to our knowledge of the dynamics of Central America.

Evidence suggests that some of the key cities that were part of the Mayan civilisation had reached a critical point whereby the impact of a severe drought could have acted as a trigger, which lead to the collapse of the whole cultural system. It is therefore the combination of a whole set of attributes in the natural and human systems, which resulted in such severe changes. The concept of time scales is important because, for example, human degradation of the landscape acts over a long time period whereas climate change can be very short lived. Even if the drying was regional in its extent the ecological and anthropological effects would have varied spatially depending on the magnitude of sub regional climate change and the sensitivity of the natural and cultural systems to environmental change (Hodell *et al.* 1995).

3.7 Conclusion

Even in the Preclassic, Mayan society was complex and sites were linked over great distances (Culbert, 1991). Populations developed rapidly which required the instigation of more intensive forms of agriculture and the production of huge amounts of stone tools in sites such as Colha. By the Early Classic this had extended to contacts in Mexico with the Teotihuacan population. Evidence for this is seen in Altun Ha. Near the end of the Early Classic there was a period of decline which Willey (1974) termed the hiatus. This period of cultural disruption did not occur evenly throughout the Lowlands with the east being least affected. It did, however, have devastating affects with civil wars and revolts and it was not until AD 650 that

the Mayan Civilisation began to function again (Adams, 1991). The Late Classic was the peak period of Mayan population and this was also the time of most elite interaction. By this time every major swamp, watercourse and lake edge in the area was being exploited (Adams, 1991). From the 8th Century the population of the Maya Lowlands was estimated to be 9-14 million (Adams, 1991). The Late Classic was a time of changing political conditions and after AD 830 there was a burst of sites that began to construct monuments close to major sites. This suggests that there were groups of elite who were taking advantage of disintegrating political situations (Culbert, 1991). The expansion of all parts of the Mayan society made it vulnerable to many internal and external stresses and ultimately to its collapse (Adams, 1991). The forces of the collapse were so great that they hindered the ability of ordinary people to survive. This implies that households were dependent on one another for their everyday needs (Blanton *et al.*, 1993).

The analysis of the palaeoenvironmental characteristics of a region and the human ecology of a prehistoric culture is complex. While the natural components can be determined, human perception and reactions to environmental change are harder to assess. The history of the Mayan civilisation in Belize highlights the importance of location (in terms of agricultural potential, defence and trade) and the power dynamics which can be developed. There has been a great deal of variability between sites due to their differing abilities to deal with changing fortunes through time. This was most apparent during the Classic period. If the climate was changing at the same time as this, the effect would be to compound the hardship that was felt by communities and collapse therefore becomes inevitable.

"Studies in palaeoenvironment are much needed to understand the Classic to Postclassic transition in northern Belize. Sediment cores and pollen samples would certainly be able to provide evidence concerning the abandonment of this region, the rate of reforestation and the degree to which the area was under cultivation from AD 850-1300" Masson (1993)

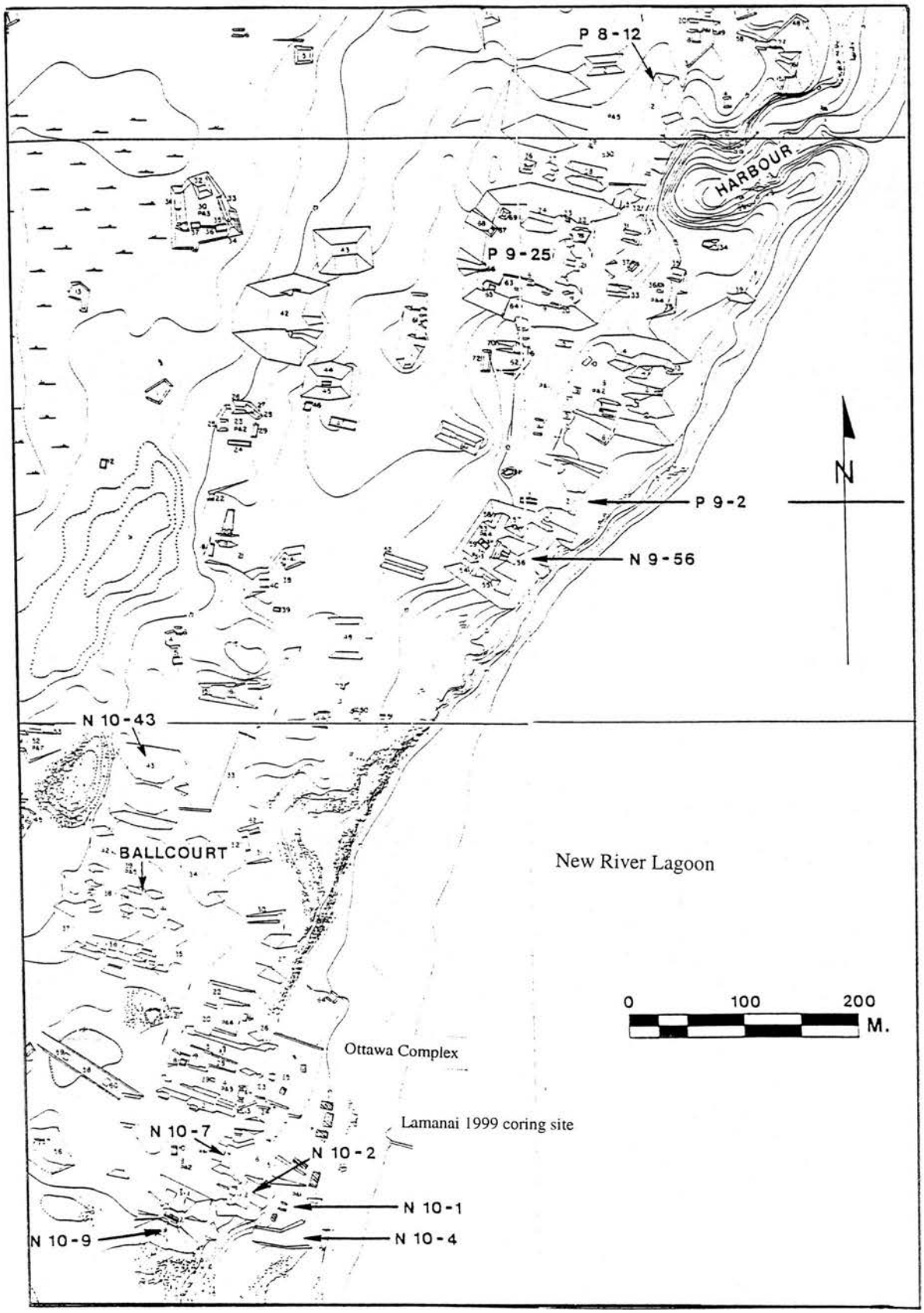


Figure 3.1 Lamanai (modified from Pendergast, 1981)

Figure 3.2 Lamanai temples

Figure 3.3

This photograph illustrates the difference between the west and east banks of the New River Lagoon.

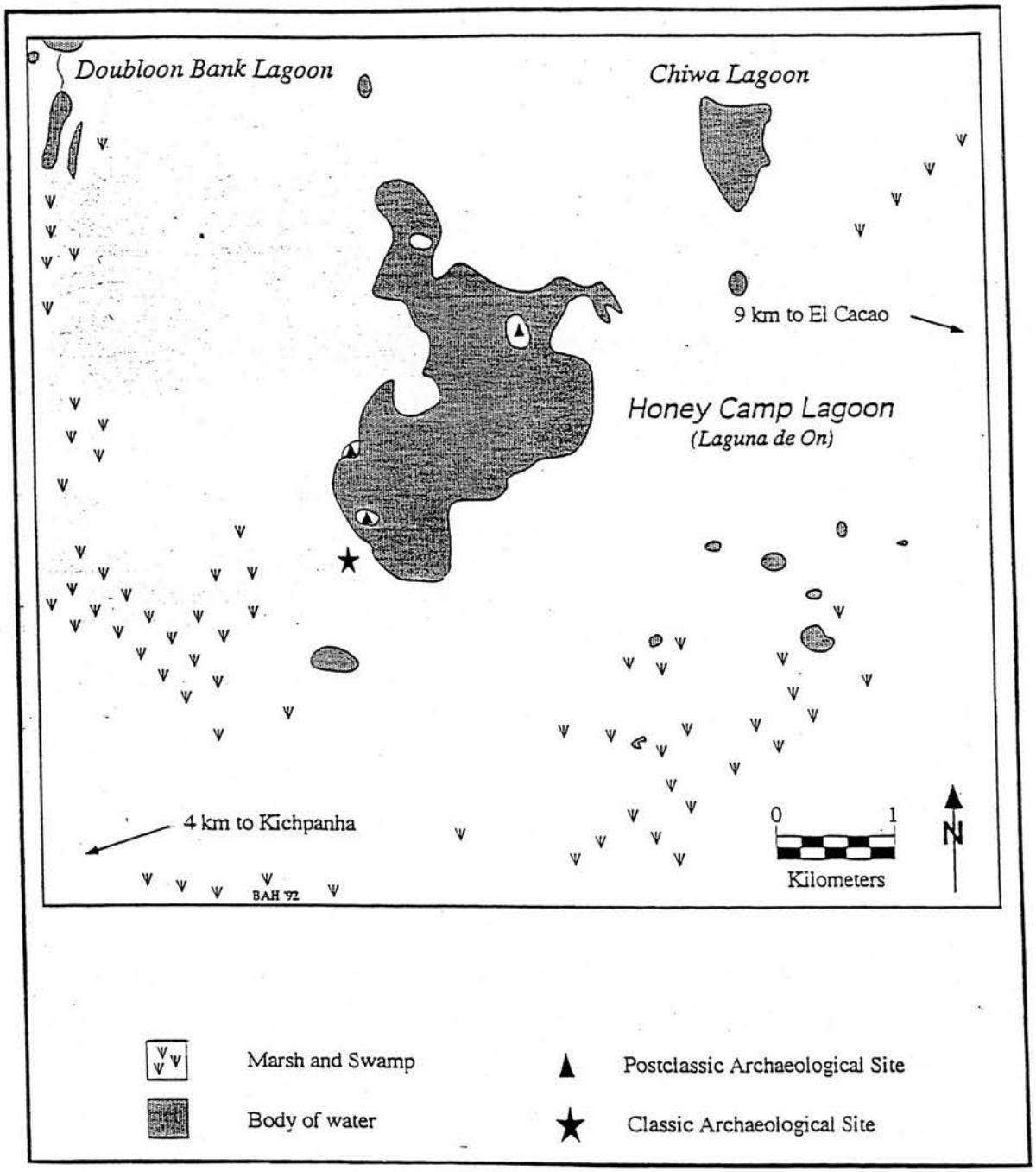


Figure 3.4 Honey Camp Lagoon (from Masson and Rosenwig, 1996)

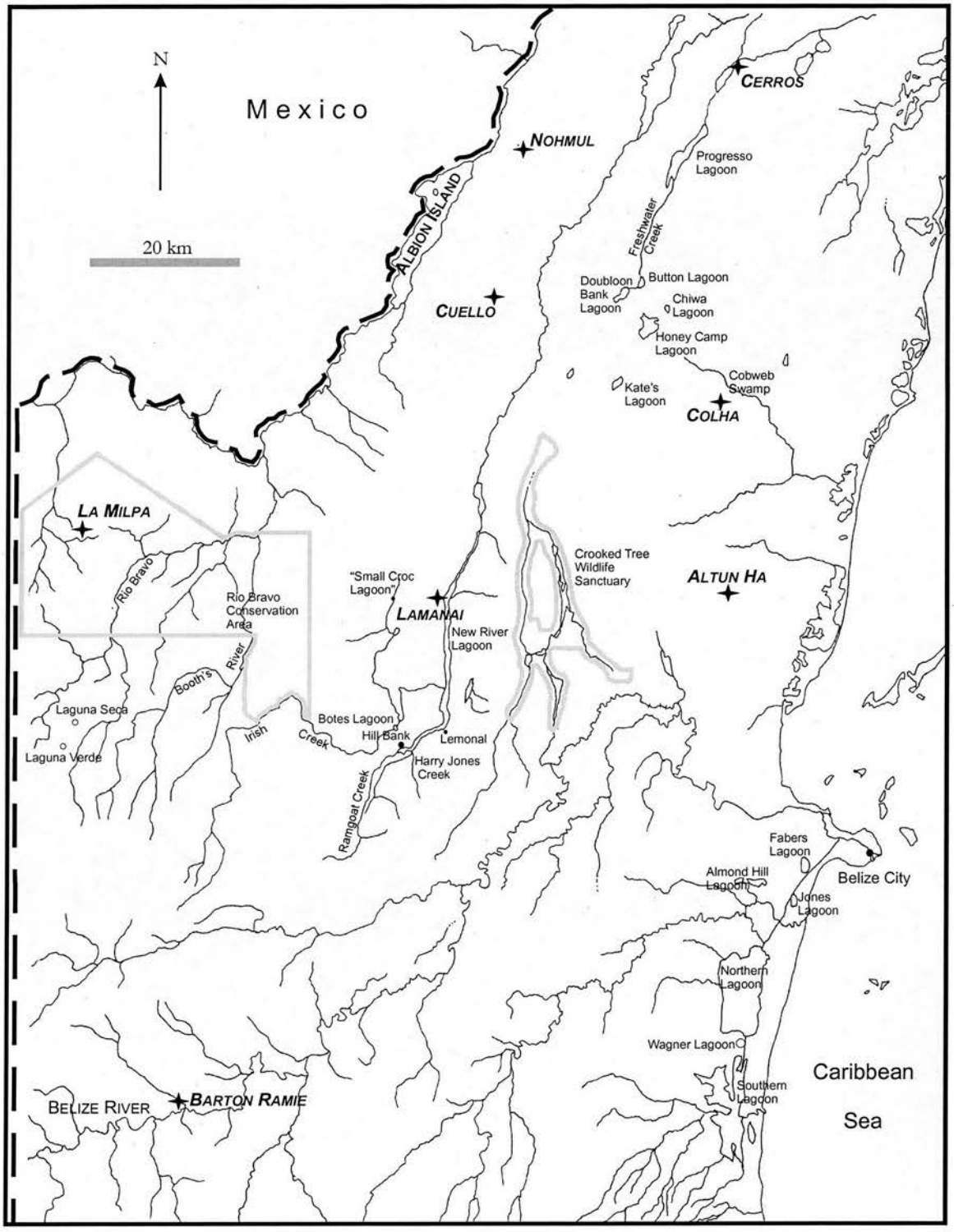


Figure 3.5 Location map of northern Belize showing the places referred to in this thesis.

Chapter Four: Techniques and Methodology

4.1 Introduction

The aim of this chapter is to describe and evaluate the methodology employed in this investigation. The two principal methods (diatom and stable isotope analyses) are discussed in detail focussing on the background behind the techniques, the development of knowledge and ideas and the specific applications to this project. Additional data were collected in a parallel project to this thesis. The results have been used to supplement this study where appropriate. The methodologies of the additional techniques are explained in this chapter. The justification of site selection and methodology are also explained as these are important steps to understanding the essence of an investigation.

4.2 Rationale

This thesis has a key set of aims which were explained in Chapter 1. The following section provides the justification for the overall choice of research approach and the two main methods that were used. Palaeolimnology is the study of past lake environments. Through the responses of a lake, information can be gathered about the external forcing factors such as climate. Lakes can be an ideal tool for this purpose, because some respond in a very sensitive manner to change and this is registered in the sediments. The responses of lakes are particular to the lake type, the climatic setting and the extent of human modification to the system. In particular it is the hydrological characteristics of a lake which determine its sensitivity to changes in climate. This has been investigated by Street-Perrott and Harrison (1985) who concluded that closed amplifier lakes were the most responsive to change. These are systems where runoff provides nearly all of the inputs to the system and there are no outlet streams. Past environments can be reconstructed by analysing the biological and geochemical elements which have been preserved in the lake sediments. These proxies are controlled by a number of different factors, which need to be understood before meaningful conclusions can be drawn (Curtis *et al.* 1998). Investigations rely

on the assumption that present day conditions and associations can be used to interpret the past.

One of the key variables to affect environments is climate change. This influences lakes in many different ways. The key changes are those which affect radiation and water balance. Radiation controls light and temperature which in turn affects the depth, duration and intensity of water column stratification. This influences many chemical and biological processes such as pH and nutrient cycling. Changes in water balance will affect lake-levels and residence times which in turn influences the structure of marginal habitats, the distribution of sediment and the ionic composition of the water body. Residence time changes will affect the availability of nutrients. All these variations are compounded by the affects that climate change have on the lake catchment as these will feed into the lake system through changes in vegetation and weathering regimes (Battarbee, 2000).

The choice of methodology is crucial to the success of the reconstruction. Diatoms and stable isotopes were chosen in this investigation for very specific reasons. Diatoms respond to changes in their environment. These changes can be due to both humans and climate change. The differences between these two forcing factors are often very difficult to unravel (Deevey, 1978; Deevey *et al.*, 1979; Vaughan *et al.*, 1985; Wiseman, 1985; Rice, 1986; Wiseman, 1990; Hansen, 1990; Bradbury *et al.*, 1990; Leyden *et al.*, 1996; Whitmore *et al.*, 1996; Islebe *et al.*, 1996a; Dunning *et al.*, 1998). Through previous diatom work in Belize (Breen, 1998) and the results of the first field season of this investigation, it was found that diatom preservation could not be relied upon to be consistent through space or time. A second technique therefore had to be employed to ensure that complete records from each site could be obtained. Stable isotopes were deemed to be ideal due to the high percentage of calcium carbonate in the sediment and secondly because they respond to different forcing factors from diatoms. This proxy has the potential to considerably widen the knowledge gained from the sediment cores analysed. Oxygen isotopes respond solely to climate while carbon isotopes provide additional information on the productivity of the lake (e.g. Curtis *et al.*, 1998).

4.3 Field methodology

The basis for this study was the collection of core material, modern diatom samples and water chemistry data during two field seasons (1999 and 2000). A total of five different water-bodies were cored and 31 sites were sampled over a variety of habitats for modern diatoms and water chemistry.

4.3.1 Coring

The sampling strategy for each field season was different. The aim of the first visit was to collect cores from a wide range of environments to enable a much more targeted programme during the second trip after the analysis of this material. The criteria for selecting the sites to return to in the second field season was primarily based upon whether diatoms were preserved or not in the sediment sequences. This applied to Hillbank and Lamanai in the New River Lagoon. Preliminary stable isotope measurements were taken at this stage and the record from Honey Camp Lagoon demonstrated a high degree of variability. This suggested the potential for a highly sensitive record of environmental change. Consequently Hillbank, Lamanai and Honey Camp Lagoon were selected for further investigation in the second field season.

A range of corers were employed to enable the successful collection of material from each site. A percussion corer was used on the shore of Honey Camp Lagoon (1999), Booth River and Aguacaliente Swamp (Figure 1.1). These were the 'solid' ground sites. In order to operate the coring device, a small motor was placed on top of the core barrel, which pushed the barrel into the sediment. A one metre core barrel was used with a plastic tube of the same length placed inside. This enabled the samples to be removed intact ready for transportation back to Edinburgh (Figure 4.1). A Livingstone corer was used to retrieve long records from the lake systems. This corer comprises a one metre core barrel which had a one metre square rod inside it with a piston at the base attached to a length of rope. This was used in Hillbank,

Lamanai, Honey Camp Lagoon (Figures 1.1 and 4.1). A Kullenberg corer was used to retrieve shorter cores with the sediment/water interface intact. This was extremely important because the top sediments in the New River Lagoon were extremely unconsolidated. The coring system could be adjusted to capture more or less of the sediment/water interface. Cores were also retrieved from Honey Camp Lagoon and Laguna Verde (Figures 1.1 and 4.2).

On arrival in Edinburgh all the core tubes were X-rayed intact at the British Geological Survey, Edinburgh. They were then cut in half lengthways using a device designed by Dr Antony Newton and Dr Malcolm Murray, University of Edinburgh. The sediment stratigraphies were then carefully noted, colour descriptions were taken from a Munsell chart and photographs were taken of the cores to form a permanent record. Half the core was then wrapped intact while the other half was cut into 1cm sections and stored in petri dishes. Both were stored in the cold store. The Livingstone core collected from Hillbank (Hillbank 1998) was collected by a team from the Natural History Museum, London. This core had only a very preliminary stratigraphy taken and unfortunately some of the one metre sections of the core have gone missing.

It is the general consensus in the literature that if a single core is to be taken then it should be from the middle of the lake where sediment disturbance is minimal and where sediment depth is likely to be at a maximum. This latter quality will increase the resolution of the record ensuring that a detailed record of change can be obtained. Subtle changes in lake volume may be amplified in marginal lake cores, although hiatuses in sedimentation are more likely (Lamb, 2000). For the two Lagoons studied in this investigation over both field seasons, cores were taken from both these locations in order to enable inferences to be made concerning whole lake dynamics. This is especially important in the New River Lagoon as it is such a large system.

4.4 Diatoms: The diatom cell - general structure and development

Diatoms are unicellular algae, which belong to the class Bacillariophyta. They are pigmented and photosynthesise. The key characteristic of diatoms is their cell wall which is highly ornamented and heavily silicified. The wall consists of two valves which are linked by girdle elements. All diatoms secrete polysaccharides which either diffuse into the medium surrounding the cell; form a capsule around the cell or create threads, pads or stalks for attachment. The two valves and the siliceous parts of the cell wall are collectively known as the frustule (Round *et al.*, 1990). Each frustule has one valve, which was formed just after the last cell division, and an older valve which may have existed for several cell cycles. The older valve, together with its girdle elements, are known as the epitheca and the newer valve and its girdle elements are known as the hypotheca (Round *et al.*, 1990).

New parts of the wall are formed within protoplasts and then added to the wall by a form of exocytosis (whereby matter is released by the living cell). The epitheca overlaps the hypotheca and cell growth occurs in one direction, forcing the epitheca and hypotheca apart (Round *et al.*, 1990). The production of new frustule components within the parental cell results in the decline of the mean cell size. Size is restored via an auxospore, which is a special cell that expands in a highly controlled way before producing a new frustule. Auxospore formation is associated with sexual reproduction (Round *et al.*, 1990). These processes result in the size of diatoms within one species being highly variable.

4.4.1 Diagnostic features of the diatom cell

There are two general forms that diatoms take: centric and pennate. Pennate diatoms are characterised by one or two longitudinal slits which run through the valve. These slits are known as the raphe, a feature which is intimately associated with movement. Some pennate diatoms are araphid and they have a silicified rib (which does not contain punctae) called a pseudoraphe. Pennate diatoms are bilaterally symmetrical and centric diatoms are radially symmetrical. Apart from these three major

divisions, it is the shape, size and valve ornamentation of the cell that are key features in the identification of diatoms. In terms of valve ornamentation it is the pores or punctae that are important. These can either be arranged linearly to form striae or they can form concentric or sector arrangements.

4.4.2 Ecology

Diatom species have specific ecological requirements. This means that particular species can be regarded as diagnostic for different types of environmental conditions. This is not a universal concept as some species are cosmopolitan being found in a wide range of environments. Due to their short cell cycle and ability to immigrate diatoms are able to respond quickly to environmental change. Factors which they are sensitive to include: habitat, water depth, nutrient availability and water chemistry. In general terms, centric diatoms are planktonic and pennate diatoms are benthic. Planktonic diatoms are free floating and due to the density of their frustule will often sink in the water column. Diatoms have a variety of mechanisms to counteract this tendency and as water bodies are rarely completely still, species are kept in suspension and within the photic zone. Benthic diatoms are associated with other substrates such as vegetation (epiphyton), rocks (epilithon), sand (episammon) and sediments (epipelon). Some species are even found in sub-aerial habitats such as in soils or damp rock faces and in moving waters (Round *et al.*, 1990). Metcalfe (1988) highlighted the importance of habitat in distinguishing between diatom populations that were from different sites with similar water chemistries. Shifts in species that can be related to habitat changes may indicate changes in the lake's morphology e.g. a shift from planktonic species to epiphytic species may indicate a drop in lake levels.

Water depth is important to diatoms as they are photosynthetic and therefore need to reside within the photic zone. Species that prefer abundant light are found in the plankton or shallow littoral zones (Patrick, 1977). The turbidity of the water body will affect this variable. Such sensitivities in the diatom record have the potential to provide an excellent addition to the record produced from the $\delta^{18}O$ record. As water

levels fluctuate (due to wider climatic changes) corresponding changes occur in habitat, light, stratification, mixing and chemical conditions. This will therefore affect the diatom species that are present (Wolin and Duthie, 1999).

The chemical composition of lake waters is of key importance in influencing the diatom species that are present. Gasse *et al.* (1995) found that it is not only ionic strength (conductivity) that diatoms respond to but also ionic composition. This allows the distinction to be made between for example carbonate/bicarbonate and chloride/sulphate systems. This therefore creates the potential to enable the reconstruction of brine evolution as waters follow particular geochemical pathways in response to evaporative concentration (Eugster and Hardie, 1970).

It can be difficult to specify one factor that has the overriding influence over a diatom population. For example Haberyan *et al.* (1997) found that magnesium concentration was very influential in determining the distribution of diatom species found in Costa Rican lakes. This element could not, however, be singled out as the most important variable because cation concentration, hardness, pH and temperature were also isolated as influential factors. Podzorski (1984) studied the diatom communities in Broad River, Western Jamaica. Many factors appeared to have an influence on community structure but again no single factor appeared to have overriding influence. Oxygen, Silica and P-PO_4, organic nitrogen and mainstream flow-rate were deemed important. This highlights the significance of investigating a wide variety of variables in the modern day environment so that systems can be fully characterised.

Different diatoms have particular nutrient requirements. This is especially pertinent in nutrient enriched environments where specific changes to species assemblages can be meaningfully related to nutrient changes (e.g. Bennion, 1994; Cooper *et al.*, 1999). It has been determined that phosphorus, nitrogen and silicon have a key influence on phytoplankton community structure and biomass. Silica utilisation by diatoms is high and diatoms can deplete natural levels to very low concentrations. Kilham (1971) postulates that diatoms need at least 0.5mg/l of silica and if levels

drop below this, other forms of algae will replace diatoms in the ecosystem. The ratio between phosphorus and silica is also a variable which species can be differentiated by (e.g. *Cyclotella meneghiana* is dominant at low levels and *Fragilaria* and *Synedra* species are dominant at higher ratios). Diatoms are rare if Si:P ratios are too low (Tilman *et al.*, 1982). Such changes may be part of a seasonal succession which lakes follow.

Due to the ecological preferences of diatoms, workers began to classify species by variables under very general headings e.g. temperature (Hustedt, 1956); pH (Hustedt 1937-39) and salinity (Kolbe 1927). In modern studies this has been done in a more quantitative manner through the development of transfer functions (e.g. Birks *et al.*, 1990; Fritz, 1990; Gasse *et al.*, 1995; Reed 1998a; Davies *et al.*, in press). Information from such studies can then be used to infer climatic and other changes (e.g. Fritz *et al.*, 1991; Laird *et al.*, 1996; Gasse *et al.*, 1997; Laird *et al.*, 1998).

The changes which are found in diatom assemblages correspond closely to shifts in other biotic communities such as other algae, zooplankton and aquatic macrophytes (Dixit *et al.*, 1992). This means that diatoms can be used as a reliable indicator of changes throughout the different ecosystems in a lake. The diatoms that are present in sediment sequences therefore provide a snapshot of environmental conditions that reflect the sum of a whole host of environmental conditions that existed at that time (Bradbury, 1999). Care, however, needs to be taken because if sample thickness is too large or sedimentation rates are extremely slow, the assemblage which is analysed may have not been an actual assemblage that existed at a particular time in the past. It will be a time-averaged sample which limits the environmental interpretations that can be made.

4.4.3 Modern sampling

In order to enable the successful interpretation of a fossil diatom record the factors which influence the distribution of the species need to be known. Ecological information is published in the literature but this is often very limited. The best way

that ecological information can be gained is through the sampling of modern diatom and water chemistry variables. This enables an understanding of the modern limnological characteristics of Belize which consequently ensures that the reconstructions of the fossil environments are as insightful as possible. To enable full characterisation of the water bodies visited samples were collected from a variety of habitats including surface sediments, vegetation and the water surface. Samples were collected and kept in zip lock bags with alcohol. The plankton samples were collected by skimming a clean water bottle across the surface of the water and stored with alcohol. Site information was also gathered including the depth of the water and the surrounding vegetation types. Water chemistry was undertaken in the field using a Palintest, which measured alkalinity, nitrate, chloride, phosphate, magnesium, sulphate and silica. In order to analyse magnesium and calcium (1999 field season) on an atomic absorption spectrophotometer, the samples were stabilised with 2ml of nitric acid and the analyses were carried out back in Edinburgh. Separate probes were used to test for pH and conductivity. The location of the sites visited for modern samples are shown on Figure 4.2.

4.4.4 Laboratory methodology for preparing diatom samples

In order to prepare samples for diatom analysis, 0.5 g of dried sediment or modern material was placed in a conical flask and 10% Hydrochloric acid was added (to remove carbonates) until the sample stopped reacting. The samples were then placed on a hot plate and 25ml of 30% Hydrogen Peroxide was then added to the samples to remove the organic matter. Once the reaction had stopped and the levels of liquid in the flasks were at a minimum more Hydrogen Peroxide was added. This continued until the reaction ceased to occur on the addition of the acid (Battarbee, 1986). The samples were then left to cool overnight. The samples were made up to 50ml with distilled water and centrifuged three times for 10 minutes at 1500 RPM. The final sample was decanted down to 30ml. 400µl was pipetted onto a 19mm diameter coverslip and left to dry overnight at room temperature. The coverslips were then permanently mounted onto slides using naphrax. The remaining solution was archived in sealed glass vials.

400 diatom valves were counted on each slide using x1000 oil immersion lens on either an Olympus BX50 or BX40. Pictures of the diatoms were taken using a Matrox Intellicam digital imaging system. Diatoms were identified using Patrick and Reimer (1966); Gasse (1986); Krammer and Lange-Bertalot (1986, 1988, 1991 a, b); Hustedt (1930 a, b, c); Germain (1981) and Foged (1984). Scanning Electron Microscope (SEM) analysis was carried out in the Department of Geology and Geophysics, University of Edinburgh on a Philips XL30-CP. Samples were prepared by pipetting solution from the archive material onto 13mm coverslips. These were then secured onto SEM stubs with carbon coated adhesive and coated in gold. The typical beam current was 60nA and the gun current was 20 KV.

4.4.5 Taxonomy

When diatoms are used in palaeoenvironmental studies there are a number of different issues that need to be considered. Two, which were of particular importance to this study were: taxonomy and dissolution of diatom valves.

Diatom taxonomy and nomenclature is extremely complex and is compounded by lack of consensus on species names. Diatoms have been recorded and classified for over two centuries but it was not until the late 19th Century that systematic and taxonomic investigations began to collect details about the distributional ecology of species (Battarbee, 1986). In the 1920s researchers began to realise the value of diatoms in palaeolimnological studies, due to their wide distribution and numbers. The correct identification of diatom species is vital to the success of a palaeoecological reconstruction of a lake system. Identification is complicated by the existence of two main schools of thought, those that take a narrow view of species and those who take a rather broader view.

The range of morphotypes (key characteristics) that are included within a species is of great importance. Confusions arise when changes in the shape and pattern of the valve that may occur in a diatom's life cycle, are not taken into consideration.

Furthermore, it has been noted that some species undergo changes in response to environmental gradients. For example, a change in salinity or silica availability influences the degree and pattern of silification in the valves (Round *et al.*, 1990). These changes are difficult to define or account for. Descriptions of species in floras usually note the extremes of the variation in length, breadth and striae density. This may not, however, be adequate if species are being identified outwith the geographical type-site area. It is also impossible to define the point at which one closely related species grades into another and thus taxonomy will always have inherent within it, bias and distortion (Round *et al.*, 1990). The working groups involved in Anonymous (1975) produced a valuable transcript proposing standardised diatom terminology. Such studies are vital in the harmonisation of taxonomic work.

As stated earlier diatom species are often described as cosmopolitan (Mann and Droop, 1996). This implies that diatom species can be found anywhere in the world where their ecological tolerances can be met. This raises a number of issues:

1. In the natural world the broad ecology of systems may be similar, but variations will exist at the micro scale. What is the response of diatoms to the specific habitats and environmental conditions in which they are found? If species respond in slightly different ways (which may be manifested in morphological differences) can these species really be regarded as the same?
2. Do truly endemic species (i.e. those which are restricted to very specific geographical areas) actually exist?
3. Do the ecological preferences of diatoms persist over space and indeed time?

The only way in which such issues can be resolved is through the extensive study of diatom species in a variety of geographical settings coupled with the collection of water chemistry, habitat and detailed taxonomic information. This should also extend to the revision of previous studies to ensure that the information available is coherent (Stoermer, 2001). This work would be a great benefit to palaeoenvironmental studies as it would ensure that accurate ecological reconstructions are being made.

A species is one or more groups of individuals which can interbreed within the groups but not with other populations. A species can be made up of groups in which members do not exchange genes such as at the extremes of a continuous geographic range. As long as some gene flow does occur along the continuum then the formation of a new species is unlikely to occur. Where physical barriers exist, this reproductive isolation may lead to genetic drift resulting in morphologically distinct subspecies developing. If the species and subspecies were introduced they would be able to breed with one another. Once this ability ceases then the two may be regarded as distinct species (Allaby, 1994). It is this definition which needs to be borne in mind when judging when a variety becomes a species in its own right.

There have been no accurate estimates of the number of diatom species. The most common figure quoted is 10,000 (Guillard and Kilham, 1977). Mann and Droop (1996) believe that with the application of modern species concepts this would be raised to 100,000. The implication of this is that there are potentially an enormous number of undiscovered or misclassified diatoms which may have a bearing on ecological reconstructions. In the last three decades new taxa have been described at a rate of 400 per year (Stoermer and Smol, 1999).

A key example of the study of varieties is *Sellaphora pupula* (Mann, 1989). Mann determined there to be at least three varieties (e.g. lanceolate with broadly rostrate ends, linear-lanceolate and linear). In the past they have been identified as belonging to the same species (Hustedt, 1930c; Krammer and Lange-Bertalot, 1986) which implies that the differences exhibited between them have little significance. Observations by Mann (1984, 1989 in 1994) have established that these varieties are in fact reproductively isolated gamodemes i.e. isolated biological species. In terms of palaeoecological studies the significance of this is upheld if it can be determined that the varieties respond to different environmental variables and therefore represent different ecological niches.

Within a palaeoecological framework such detailed analysis of species is not possible unless collaborative projects are undertaken. This would be especially valuable where studies are being undertaken in new areas where very little is known about the modern diatom populations. Close taxonomic studies would ensure that the palaeoecological interpretations which are made, are as accurate as possible. Mann (1999) believes that different forms of species which are separated geographically are probably separate species even though some stages of the respective life cycles may be indistinguishable. The affinities of these intermediate forms can only be determined with any certainty if the whole life cycle is known or if the taxonomist has a good understanding of the biogeography and ecology of the area. Such associations would move diatomists away from the tendency to fit their taxonomy into European and American floras enabling a true understanding of species to be developed.

Closely related taxa do often differ ecologically (Gasse, 1986) and thus it should not be deemed unlikely that varieties of the same species could also exhibit differences in the field. The ecology of taxa (especially *Aulacoseira*) studied by Haberyan *et al.* (1997) in Costa Rica differ from those found in the United States and East Africa. Davies *et al.* (in press) found that derived conductivity optima for species in Mexico generally compared well with the African data set (Gasse *et al.*, 1995) but there are some differences, especially at the higher end of the conductivity range. For example, *Cyclotella meneghiana* 2,980µS cm^{-1} (Mexico) and 6,010 µS cm^{-1} (Africa); *Navicula halophila* 19,050 µS cm^{-1} (Mexico) and 2,980 µS cm^{-1} (Africa) (Davies *et al.*, in press). These could simply be a function of the differences in the data set sizes or actual variations in the ecology of the species which have evolved due to the geographical distinctions between Mexico and Africa. Differences are also noted between Spain and Africa (Reed, 1995). For example, *Nitzschia amphibia* has an optimum tolerance of 8300 µS cm^{-1} in Spain whereas in Africa it is much lower at 500 µS cm^{-1}. The three studies from Africa, Mexico and Spain are transfer functions i.e. they can be used to reconstruct environmental conditions. If species are found to have different tolerances in distinct areas it means that the same data set will have different reconstructed conditions depending on the transfer function used. This

highlights the point that species thrive in potentially divergent conditions in different areas. In order so that the reconstructions that are made are accurate, the transfer function applied should therefore be from either close to the study site or from a similar environment. The more modern diatom based studies that are conducted, the greater our understanding will become regarding the environmental requirements of species.

All these issues are particularly relevant to this study because diatom work has not been undertaken in Belize before. Although the species encountered were found in the general literature, some differences were noted. It was therefore decided to conduct a more in depth study of one of the most common species *Mastogloia smithii* var. *lacustris*. The details of this are described in Chapter 5.

4.4.6 Dissolution

A key assumption of palaeoecological studies is that the fossil record preserved in the sediments is a faithful representation of the community which existed at the time of deposition. There are, however, a host of factors which can interrupt this process, both in the water column and in the sediments. One of these processes is dissolution. The dissolution rate of a particular species can be explained by variables such as the degree of silicification, the extent of sculpturing and the specific surface available for dissolution (Barker, 1992).

It has been found in many diatom studies that dissolution is a problem. It is very important to ascertain why this is the case especially if the level of preservation changes through time. The most common explanation given is post-depositional dissolution of frustules at times of high pH (greater than pH 9.0) (e.g. Bradbury *et al.*, 1981). The diatom free sediments found in Bradbury's study of Lake Valencia, represented a time of low lake level. This may have allowed meromixis (lack of overturn in the water column) where the carbonate-rich, hypolimnetic water may have had a pH in excess of pH 9, which would have resulted in the complete dissolution of the diatoms. This is not a fixed rule because if there is high silica

availability, diatoms can survive high pH conditions. Poor diatom preservation is a problem in the record from Lake La Yeguada, Panama (Bush *et al.*, 1992). The water chemistry throughout the history of this lake has been dilute and carbonate levels low. The reasons behind poor diatom preservation in this system are problematic. Lake levels at the time of poor diatom preservation were high meaning that solute concentration through evaporation is unlikely. The deep lake could have been stratified resulting in a permanently anoxic hypolimnion and biogenic meromixis but, such effects should be picked up in the chemistry of the sediments and biogenic meromixis in the absence of carbonates is more likely to lower pH than raise it. A drop in silica is unlikely as sponge spicules are present. It could be that strongly oligotrophic conditions resulted in diatoms being outcompeted by other phytoplankton groups. Such groups have not, however, been preserved to prove this hypothesis (Bush *et al.*, 1992). This example highlights the importance of knowledge about the whole lake system so that reasonable hypotheses can be generated with regard to changes in environmental conditions.

If there is a high quality of diatom preservation in the surface sediments this indicates that diatom silica dissolution within the lake waters, prior to deposition, is not an important forcing factor (Reed, 1995). If modern samples are fragmented, however, this will increase the chances of post depositional dissolution occurring because of the greater surface area available for dissolution. Fragmentation is caused by different processes than dissolution. The absence or poor preservation of diatoms in surface sediments implies that post depositional taphonomic processes operate very rapidly (Reed, 1995). The chance of this situation arising is greatly enhanced if the lake system is not permanent.

As a general rule diatom preservation is better in acid rather than alkaline systems and it is the form of carbonate in these latter systems that is of key importance (Flower, 1993). Preservation should decline as the activity of the metal species increases. Dissolution is caused by hydrolysis of the metal carbonates, which produce hydroxyl ions that attack Si-O bonds in the diatom cell wall (Stumm and

Morgan, 1970). Preservation should therefore decrease from calcium, magnesium and sodium carbonate dominated systems (Flower, 1993).

In general terms the factors which influence the dissolution of a diatom cell fall into two categories. The first are the characteristics of the water body itself. These include temperature, pH, ionic concentration and composition, the concentration gradient of the dissolved SiO_2 between the sediment and water, water depth, turbidity, diagenetic processes which are related to groundwater movement, dissolved silica diffusion rates, the interstitial dissolution of silica and the sediment accumulation rate. The coarseness of the sediment, grazing and bioturbation will also have an affect. In shallow lakes, mechanical breakage from turbulence and desiccation are key processes (Ryves, 1994; Reed, 1998b). Flower (1993) notes that diatom valves have a tendency to become highly fragmented in shallow, turbid waters and are better preserved in sheltered lakes with macrophyte beds and a higher sedimentation accumulation rate. The second category is the characteristics of the diatom cell. These include the silica content of the cell wall and the availability of polyvalent cations for adsorption to the cell wall to provide a protective coating (Battarbee, 1986).

Diatom silica dissolution is a potential problem in all lakes, but it only becomes an issue where the parameters of dissolution rate and the reaction time are high. As described above there are a number of specific factors which predispose a system to dissolution, but it also occurs in situations where low specific kinetic rates of dissolution act over extended periods of time. In systems which have a high sedimentation rate, the preservation of the diatoms is promoted (Flower, 1993). Where diatoms sediment over large distance in undersaturated water or when the pore-water silica levels cannot be maintained at saturation levels then dissolution will be the main process which acts on the diatoms (Ryves, 1994). It is in lake systems such as these that extrapolating the relationship between the living flora and the modern sediment assemblage is not simple. This especially affects fragile taxa (e.g. *Nitzschia frustulum*) whose distribution is intimately linked with dissolution processes rather than environmental gradients (Ryves, 1994). With regard to

sediment records, problems begin when there is partial preservation of the sequence as this will lead to bias in the record towards the more hardy species.

A key factor, which must be taken into consideration, is that techniques in the laboratory can contribute to the poor state of diatoms. Vigorous acid oxidation will destroy fragile diatom valves and make the valves more prone to dissolution (Flower, 1993). Rapid centrifuging and drying is known to affect long species especially and indeed the drying of sediments before these processes begin will result in damage, due to sediment shrinkage (Flower, 1993).

Barker (1992) observed a number of stages which diatoms move through when being dissolved. Firstly valves will become relatively transparent as a result of the enlargement of the structural pores. Poorly silicified features are then lost (such as the valve margins) leaving behind the stronger central areas. The surface area:volume ratio and basic shape of a diatom cell influences its ability to dissolve, for example, *Nitzschia* species begin dissolution at their apices whereas in centric species, the delicate margins disappear first leaving behind a featureless disc (Barker, 1992). Structures with high surface area:volume ratios such as pore fields and areas with a high striae density tend to dissolve preferentially to those with low ratios such as central areas. Raphes often act as a line of susceptibility in the resistant apical zones (Ryves, 1994). It is difficult to follow the dissolution process because diatoms become much more prone to breakage once dissolution has begun.

Ryves (1994) formulated a series of dissolution stages which particular diatom genera appear to follow. This is valuable information to gather when assessing the preservation of a sample and crucial to the creation of a meaningful palaenvironmental reconstruction. These stages can then be fed into dissolution indices that can be used to investigate the preservation of samples. These are Flowers DDI, Weighted Index and Square Weighted Index (Flower and Likhoshway, 1993; Ryves, 1994). Flowers DDI is a uniform index varying from 0-1 (the latter being perfect preservation). This index allows the comparison between any samples, but, it is not as sensitive to highly dissolved samples. Weighted and Square weighted

are only comparable for taxa which have the same number of dissolution stages. The square weighted index as compared to the weighted index emphasises the non-linearity between the degree of sample dissolution and the proportion of diatoms in the highest dissolution stages (Ryves, 1994; Ryves and Battarbee, unpub).

Square Weighted = (a*1+ b*4+c*9+d*16)/ (a+b+c+d)

Weighted = (a*1+b*2+c*3+d*4)/(a+b+c+d)

DDI = a /(a+b+c+d)

Where a = dissolution stage one

b = dissolution stage two

c = dissolution stage three

d = dissolution stage four

Dissolution indices can only be applied to taxa which have an identifiable end stage (d). This encompasses genera such as *Cymbella*, *Mastogloia* and *Cyclotella*. Other species either completely disappear or have featureless end stages that are impossible to identify and therefore cannot be used (Ryves, 1994).

To ensure that dissolution indices were applied in the most appropriate manner it was decided that a small investigation should be carried out. Only the top 11cm of the Honey Camp 1999 sequence (Figure 4.3) preserved diatoms. Such a shift suggests that there has been a significant change in the system. The study of diatom dissolution provides a great deal of information in terms of the magnitude and timing of the change in the system. In more general terms it allows inferences to be made concerning the effects of the degree to which species are silicified and the implications which this has for using one species as a guide. The use of one species is employed on the longer records from the New River Lagoon.

The investigation of had two main aims:

1. To investigate the difference in preservation status between different species.

2. To use this information to provide preliminary information about Honey Camp Lagoon.

Although diatoms were preserved in the top 11cm there is a great difference between the top 5 and bottom 6cm of the record in terms of diatom concentration. Figure 4.3 is the graph of diatom concentration which clearly shows the higher levels at the top as compared to the bottom of the sequence. In order to gain a meaningful idea of the differences between species, dissolution indices were applied to the counts from the top 5cm.

The dissolution indices are based on the amount of diatoms at particular stages of dissolution at each level. The stages for the species used in this investigation are shown in appendix 1. In general terms, there are four stages of dissolution that a particular species will go through. These stages are based on the morphology of the diatom and it has been demonstrated that species do follow distinct stages between perfect preservation and complete dissolution (Barker *et al.*, 1990; Barker, 1992; Flower, 1993; Ryves, 1994; Ryves *et al.*, 2001).

Figure 4.4 shows the dissolution indices for the species investigated. The following points can be made immediately:

1. *Mastogloia smithii* var. *lacustris*, *Denticula elegans* and *Navicula radiosa* all show very similar results.
2. The record from *Brachysira neoexilis* is different with this species showing best preservation when the rest of the species were at their worst.
3. *Denticula elegans* is obviously slightly more robust than *Mastogloia smithii* var. *lacustris* and *Navicula radiosa* because it takes slightly longer to drop to lower preservation levels.
4. The DDI index appears to be the most sensitive because it highlights changes between the zones rather than the smooth curve of the weighted and square weighted indices.
5. The key problem with the DDI index is that it records a zero value when there are no perfectly preserved valves meaning that information can be lost.

In order to determine how the robust species are, the DDI score for each species was plotted against the percentage of that species in each level (Figure 4.4). This clearly shows that *Mastogloia smithii* var. *lacustris* is the most robust because it is able to reach high percentages at low DDI scores. From this information and the fact that it showed a similar pattern of dissolution to *Denticula elegans* and *Navicula radiosa* it was decided that *Mastogloia smithii* var. *lacustris* is a suitable species to provide a great deal of information about the general diatom preservation status of a record. Although dissolution rates are specific to species it has been demonstrated that a common species can be representative of the system (Barker, 1992; Barker, 2000 pers.com).

4.4.7 Data presentation

Two diatom records were produced and the percentage diatom diagrams for the sediment cores have been created using TILIA and TILIAGRAPH (Grimm, 1992). CONISS (Grimm, 1987) was used to identify the diatom zones. This is a stratigraphically constrained clustering programme within TILIA.

4.4.8 Statistical methodology

In order to quantify the trends which have been found in both the modern and fossil diatom data sets analysed, particular statistical techniques have been applied. Ordination describes multivariate techniques that arrange samples along an axis on the basis of species composition. This results in a graphical representation of the data where sites are represented by points in space. The aim of ordination is to arrange these points so those samples that are similar in species composition are located close together. This is a good technique for organising large data sets as it is very effective in showing relationships, reducing noise and identifying outliers (Gauch, 1982).

For each axis an eiganvalue is produced which summarises the amount of variance which the axis accounts for. The axes are then ranked according to their eiganvalues,

with the first axis having the greatest value. The ordination diagram produced can only be interpreted in terms of what is known about the environment of the site. If explicit environmental data are not available, the interpretation must be done in an informal way. If, however, it has been collected, direct gradient analysis can take place. When using direct gradient analysis one is interested from the beginning in particular environmental variables and their specific influence on the system.

This study employs two main types of ordination methods. Firstly, Detrended Correspondence Analysis (DCA) which is where the structure of a single data set is described. This is an indirect form of ordination. Secondly, Canonical Correspondence Analysis (CCA) which uses environmental data to explain the data set and is therefore direct gradient analysis. These can be can be accessed as part of the Canoco programme (ter Braak, 1987-1992). DCA was devised by Hill and Gauch in 1980 (Kent and Coker, 1992) in order to attempt to solve the 'arch effect' of Canonical analysis, by detrending (Jongman *et al.*, 1995). DCA extracts the dominant pattern of variation in the community composition from the species data. CCA is different from other ordination techniques, in that it selects the linear combination of environmental variables which maximise the dispersion of the species scores. Thus it incorporates the relationships between species and environment in the actual ordination itself rather than by superimposing environmental data onto ordination plots. The joint plot of species points and environmental arrows is a biplot, which approximates the weighted averages of each species with respect to each of the environmental variables.

4.4.9 Transfer function

In order to quantify the changes in the diatom population a transfer function was applied to the core data. For a number of regions around the world modern calibration data sets have been produced. These are created through the collection of modern sediment samples and water chemistry variables with species optima being estimated using regression techniques. These are now very sophisticated and include estimates of error and validation (Birks, 1998). This investigation is the first

comprehensive study of both modern and fossil diatoms in Belize. The water chemistry variables collected in association with this data were not adequate to develop a transfer function. Reed (1995) developed the model (which was employed in this investigation) for lakes in Spain. The reconstructed variable is conductivity. This transfer function was chosen because it contained most of the species which were found in the Belize data sets. Issues related to transfer functions were raised in section 4.4.5. These will therefore have to be considered in the interpretation of the results. The application of training sets to core material can also be problematic if for example there is poor diatom preservation (Barker *et al.*, 1990; Ryves, 1994; Reed 1998b) or if the fossil diatoms are not present in the modern day environment (Davies, 2000).

From the evidence presented in this chapter it is apparent that diatoms are a powerful tool in terms of reconstructing environmental change. They provide information concerning whole lake ecology e.g. water balance, vegetation change and chemical composition. With all this information a number of issues have to be taken into consideration:

1. The relationship between the modern environment and the palaeo environment.
2. Issues of species identification and the applicability of this over space.
3. The processes which influence the preservation of diatoms.

The key point is that if all the issues are considered then diatoms are an extremely insightful tool.

4.5 Stable isotope analysis: Introduction

Stable isotope analyses are being employed in this investigation to enable the reconstruction of changing levels of evaporation/precipitation (through oxygen isotopes) and lake dissolved inorganic carbon levels (through carbon isotopes). The aim of this section is to provide a background on the theory behind stable isotope analysis; the controls which act on the bulk carbonate/gastropod records and the behaviour of isotopes in the modern environment. This information will enable an informed interpretation of the results which have been gained in this study.

Isotopes are atoms whose nuclei contain the same number of protons but a different number of neutrons i.e. ^{16}O, ^{17}O, ^{18}O. Thus, isotopes of the same element will have slight differences in mass and energy which results in differences in physical and chemical properties (Tucker and Wright, 1990). Results from isotopic studies are reported in ratios, as the absolute abundance of heavy isotopes is low. The values from the sediments are compared against baseline standards, which have been assigned zero per mil on the δ scale. Low temperature carbonate and organic materials are compared against Peedee Formation Belemnite (PDB) (Craig, 1957). Water is compared against Standard Mean Ocean Water (SMOW) (Craig, 1961). The trends in isotope records are referred to as enrichment or depletion relative to the standards.

The measured difference between the standard and sample is reported in terms of a δ-values where:

$$\delta = (R_x - R_{std}) / R_{std}.1000$$

R = isotope ratio i.e. $^{18}O/^{16}O$.
(1000 converts δ-values to per mil (‰)).

Urey (1947) first proposed that oxygen isotopes could be used to give an idea of palaeotemperatures. Freshwater carbonates were not thought to be suitable for such considerations. It has since been found that the change in the ^{18}O content of water, due to climatic change, is much larger in freshwater reservoirs than it is in the ocean. This suggests that it is possible to use oxygen isotope ratios to estimate temperature changes and other climatic forcing in the freshwater environment (Stuiver, 1970). Carbonate minerals, which have been precipitated under equilibrium, will have an isotopic composition that reflects the isotopic content of the system. This relationship is known as isotopic equilibrium. Therefore, the stable isotope compositions of fossil limestones and shells contain within them information about past environments.

4.5.1 Controls on oxygen isotopes:

The dominant control on the $^{18}O/^{16}O$ ratio in tropical lakes is evaporative fractionation which is controlled by temperature and humidity. Annual temperature ranges in the tropics are small (section 1.3) and therefore the effect of temperature on the isotopic composition of carbonate is negligible (Gat, 1980). Providing there are no changes to mineralogy then changes in $\delta^{18}O$ can be linked to the ratio of evaporation to precipitation (Fontes and Gonfiantini, 1967; Covich and Stuiver, 1974; Gasse *et al.*, 1990; Talbot, 1990; Lister *et al.*, 1991). The degree of change is very much dependent on the lake hydrology, with closed basins being the most responsive. Within open systems, groundwater flux will have a substantial affect (Bridgwater *et al.*, 1999). In lakes with a rapid through-flow of water, the isotopic composition of the lake water may reflect the mean inflow, such as precipitation and groundwater. Such information is useful as the composition of meteoric water varies according to its origin and climatic evolution (Rozanski *et al.*, 1993). The term meteoric water includes glaciers, groundwaters, surface and atmospheric waters (Leng, unpublished).

During times of high evaporation to precipitation (i.e. a dry climate), the ratio of $^{18}O/^{16}O$ in lake-water (and in the carbonate precipitated in equilibrium with the lake-water), will increase as the lake volume decreases. Conversely, periods of low evaporation to precipitation (i.e. a wet climate) will be marked by low $^{18}O/^{16}O$ ratios and increasing lake volumes (Curtis *et al.*, 1996).

The key control on the $^{18}O/^{16}O$ in lake water is generally the oxygen isotope composition of the rainfall supplying the lake. The isotopic composition of the precipitation is controlled by the source area of the water vapour; the fraction of the water vapour remaining at the time of precipitation; the amount of evaporation that occurs as the rain falls through the atmosphere and the temperature of condensation (Curtis *et al.*, 1996). Curtis *et al.* (1996) in their study of Lake Punta Laguna assumed that these affects had been small during the late Holocene relative to the

main control of lake water $\delta^{18}O$. The main control on this is the fraction of the lakes water budget which has been lost to evaporation which, in turn, is affected by lake residence time (Stuiver, 1970).

Changes to the level of precipitation and surface flow will also influence the transfer of dissolved and particulate material to the lake. Changes in the flux of materials to the sediments are a result of variations in the material output of the catchment. The key factor that would influence this is land-use change. Forest clearance and high rainfall accelerate alluviation and colluviation as well as altering the transport of soil nutrients, organic and inorganic matter to the lake. Forest removal will also decrease evapotranspiration and soil moisture storage in the watershed. This will increase the catchment water yield and the transport of isotopically light surface and groundwaters to the lake. To gain a complete understanding of the $\delta^{18}O$ record the role of vegetation in controlling the lacustrine hydrologic budget should be assessed (Roseinmeier *et al.*, in press).

4.5.2 Controls on carbon isotopes:

In the same manner as oxygen, carbon has three isotopes ^{12}C, ^{13}C and ^{14}C. It is the ratio between ^{12}C and ^{13}C that provides the $\delta^{13}C$ signal. Records produced from carbon isotopes are much more problematic to unravel than those from oxygen isotopes. Consequently, very detailed information on the modern day carbon sources are required. Variations in the $^{13}C/^{12}C$ ratio of authigenic carbonates reflect changes in the $^{13}C/^{12}C$ ratio of the Total Dissolved Inorganic Carbon (TDIC) pool. This in turn is dependent on the temperature of carbonate precipitation; the degree of equilibration with atmospheric CO_2 (which is determined in part by residence time); the ratio of aquatic productivity to organic matter decay within the lake; microbial activity and groundwater inputs (Durazzi, 1977; McKenzie, 1985; Chivas *et al.*, 1993; Heaton *et al.*, 1995).

Aquatic photosynthesis results in the preferential assimilation of ^{12}C into organic

matter leaving the surface water TDIC pool enriched in ^{13}C. CO_2 exchange between the lake TDIC and the atmosphere will also enrich $\delta^{13}C$. This process becomes more important as water residence time increases. Inputs of freshwater and the oxidation of organic matter will result in the depletion of ^{13}C in the TDIC reservoir (Lamb, 2000). There is also a tendency to equilibrate with atmospheric CO_2 through gas exchange ($\delta^{13}C$ -7‰) (Holmes *et al.*, 1997).

Lake volume changes may play a role on the effect which CO_2 exchange has on carbon isotope fractionation. A rapid increase in lake volume reduces CO_2 exchange between lake water and the atmosphere which causes the lake $\delta^{13}C$ to approach steady state more slowly, evolving towards a value which is lighter than under average conditions (Li and Ku, 1997).

Carbon isotope studies can also be undertaken on the organic carbon in the sediment. This provides an indication of the carbon source into the system. There are two photosynthetic pathways which plants can follow: C3 Calvin pathway (lowland forest trees) and the C4 Hatch-Slack pathway (grasses) (Meyers, 1994). These have discernible isotopic signatures with C3 plants occurring between $\delta^{13}C$ –22 to-33‰ and C4 plants between –9 to –16‰. The signals, which come from submerged aquatic macrophytes and algae, are less distinct with both having large and overlapping ranges (Holmes *et al.*, 1997). As already described if there is a shift in the catchment vegetation then this will influence the $\delta^{13}C$ signature of the organic matter. Oxidation of terrestrial organic matter generates CO_2 that has an isotopic signature that is akin to the source material. Some of this CO_2 will enter the groundwater and once this reaches the lake it will influence the isotopic ratio of the lake water DIC (Curtis *et al.*, 1998).

4.5.3 The relationship between carbon and oxygen isotopes:

Every lake is different and will respond to the same external forcing in diverse ways. The records from each lake will, in turn, be different. Inferring regional change from individual systems is therefore difficult. Through work which has been undertaken it

has become apparent that there are a number of trends which are common to particular types of lake (Talbot, 1990). One such trend is for the carbon and oxygen isotopic ratios to covary. Isotopic covarience is most typical of carbonates from lakes which are hydrologically closed (Talbot, 1990). The R^2 value for the correlations in such systems is greater than 0.7. Carbonates precipitated during periods of high lake levels will plot towards the negative end of the trend and those precipitated during low lake levels will be towards the positive end (Talbot, 1990). The persistence of a covarient trend through time implies that the isotopic composition of the inflow to the system is stable, as is the response of the basin to changes in the precipitation to evaporation ratio (Talbot, 1990).

What drives the covarient trend? As lake volume declines due to net evaporation, $\delta^{18}O$ will increase as ^{16}O is preferentially lost from the system. It also results in the increase of $\delta^{13}C$ for the lake dissolved inorganic carbon. This increase is the result of three main effects:

1. Freshwater is usually more depleted in ^{13}C than lake water, therefore, in times of high evaporation, photosynthetic removal of organic carbon leads to the increase of lake $\delta^{13}C$, even if productivity remains unchanged.
2. Strong evaporation raises pCO_2 of the lake, resulting in a net loss of CO_2 to the atmosphere with lighter $\delta^{13}C$ than the lake water $\delta^{13}C$.
3. The mixing across the thermocline or chemocline of a lake which supplies nutrients from deep water to the euphotic zone where phytoplankton grow. This increased vertical mixing enhances surface productivity leading to elevated $\delta^{13}C$ values for the lake DIC.

   (Li and Ku, 1997).

These relationships do not hold true in open systems. Basins with rapid throughflow will reflect the composition of the inflowing water and hence often have narrow calcite $\delta^{18}O$ ranges. The variations which do occur reflect small changes in temperature and inflow-precipitation balance between the periods of carbonate precipitation (Talbot, 1990). $\delta^{13}C$ records show wider ranges due to variations in photosynthesis rates (Stuiver, 1970; McKenzie, 1985).

4.5.4 The contemporary environment:

Knowledge of the present day dynamics is key to the understanding of the palaeoenvironmental record. Ocean waters have a $\delta^{18}O$ value of 0 +/- 1‰. Values of surface waters around the globe differ from this due to evaporation, formation of sea ice and the addition of meteoric water. The physical processes which are responsible for the production/transport and condensation of atmospheric water vapour, cause large variations in the isotopic ratios of meteoric water. The total range of $\delta^{18}O$ in natural precipitation is +4 (tropics) to –62‰ (Antarctic) (Leng, unpublished).

Hydrogen has two isotopes: ^{2}H or D (Deuterium) and ^{1}H. A water molecule containing D or ^{18}O is heavier than a normal $^{1}H^{1}H^{16}O$ molecule. Water vapour forming precipitation will be depleted in heavy isotopes relative to ocean water. Condensation forming raindrops from a cloud reverses this process. The heavier molecule condenses first i.e. rain is isotopically enriched and the cloud moisture is subsequently depleted as the rainout continues. This series of isotopic fractionations is temperature dependent and therefore a water sample has a particular isotopic signature depending on the environmental conditions it has experienced.

The climate of the Tropics is distinguished by the distinct wet and dry seasons which divide the year. In mid to high latitudes precipitation is isotopically depleted in the winter and enriched in the summer. These differences are due to a number of factors which include the changes in temperature between winter and summer and the seasonally changing source areas of storm trajectories. In general terms the precipitation in polar regions is isotopically lighter than in low latitudes. In the Tropics, however, the seasonal fluctuations in $\delta^{18}O$ and δD have a different origin. The main correlation is with the amount of precipitation, with isotopically depleted precipitation occurring in the rainy season (Rozanski *et al.*, 1993). This association was first recognised by Dansgaard (1964) and is referred to as the 'amount effect'. There is no relationship with temperature as this varies very little in the Tropics throughout the year.

The key point is that surface waters preferentially lose the lighter water molecules due to evaporation and thus are often enriched compared to the rainwater from which the surface waters were formed (Global Network for Isotopes in Precipitation, 2000).

Craig, 1961 discovered that there is a linear correlation between δ^2H and $\delta^{18}O$ for meteoric water whereby:

$\delta^2H = 8\ \delta^{18}O + 10$. This is known as the Global Meteoric Water Line (GMWL). Deviations from this slope are caused by evaporation. This occurs mainly in low latitudes and semi-arid regions. The position of rainfall along the GMWL is dependent on the timing and duration of rainfall as well as temperature, humidity and altitude. There will therefore be seasonal differences in the values (Lamb, 2000).

Since 1961, the International Atomic Energy Agency (IAEA) and the World Meteorological Organisation (WMO) have conducted a worldwide survey of hydrogen and oxygen isotopes in precipitation (Dansgaard, 1964). From the collection of these data it has been possible to deduce circulation patterns and the mechanisms of global and local water movements.

Data have not been collected for Belize, but have been in the neighbouring locations of Veracruz, Mexico; Havana, Cuba; Puerto Rico; Panama and the Dominican Republic. In order to enhance the interpretations which can be made from the ^{18}O record it needs to be determined whether, in the modern day environment, there is a relationship between the ^{18}O of precipitation and the amount of precipitation for the same period. Data from monthly precipitation totals and average ^{18}O values have been plotted as scatterplots (Figure 4.5). The only area which has an R^2 value of greater than 0.5 is the Dominican Republic. This implies that this is the only region where the 'amount effect' holds true. If this is the case then this has severe implications for the interpretation of isotope records because the controls over the isotope signal are not clear. There are however a number of reasons why the relationship does not hold in the other sites. It could be a function of the years which the data are from i.e. those years may not have had a particularly distinct wet and dry

season. The sites where the data have been taken from may have local environmental factors such as a mountain range which would affect the signal. The accuracy and reliability of the data are also not known. The values are averages (as these are the only data available) and therefore the signal is also likely to be dampened. This study highlights that a degree of caution needs to attached to interpreting results and shows the importance of collecting modern data so that these relationships can be determined for the area that is being studied.

4.5.5 Methodology

In order to gain an idea of the modern water isotope values in the New River and Honey Camp Lagoons, modern water samples were collected. These were kept in a sealed water bottle which was kept as cool as possible. The samples were analysed for $\delta^{18}O$ and δD by Mr Andrew Tait at the Scottish Universities Environmental Research Centre, East Kilbride.

4.5.6 Bulk carbonate record:

The stable isotope results in this study have been obtained from both bulk carbonates and individual gastropods. In order to fully understand the results that have been derived, it is important to appreciate the governing mechanisms which control the isotopic signature from both the gastropods and the bulk carbonates. Authigenic calcites are precipitated mainly during the summer due to increased algae and macrophyte photosynthesis in the epilimnion. Algae have seasonal blooms during which time the dissolved CO_2 in the lake waters is depleted inducing carbonate precipitation.

Carbonate ions in lake water form as a result of the dissolution of CO_2 which when partially hydrated exist as carbonic acid (H_2CO_3). The disassociation of H_2CO_3 produces CO_2, HCO_3^- and CO_3^{2-} the relative proportions of which are dependent on pH. Precipitation of carbonate occurs either due to an increase in temperature or due to a decrease in the partial pressure of CO_2 (due to its removal from the lake). As

temperature has only a small affect on carbonate supersaturation, CO_2 removal is generally more important (Tucker and Wright, 1990). A common way to remove CO_2 is by photosynthesis and therefore most inorganic carbonate precipitation is biologically induced. The reduction of CO_2 from the lake will slowly be replaced via exchange with atmospheric CO_2 until equilibrium is restored. The isotopic signal, which is recorded, is that of surface conditions which will be more sensitive to changes during the annual cycle than material from deeper locations (Leng, unpublished).

Biogenic and inorganic carbonates are authigenic if they have been precipitated within the lake itself and thus are the most useful material to use as they reflect conditions in the lake at the time of precipitation. Authigenic carbonate therefore records average trends but will be weighted towards summer conditions when, as explained earlier, most precipitation occurs.

Bulk carbonates were used in this study and these are made up of:

1. Detrital carbonate derived from the catchment via rivers and shoreline erosion including reworked lacustrine carbonates which have become exposed during falls in lake level.
2. Biogenic carbonate derived from various organisms including molluscs.
3. Diagenetic carbonate produced by post-depositional alteration of other carbonate minerals.

(Tucker and Wright, 1990).

A complication to the bulk carbonate record is fractionation. This occurs when there is a change in the ratio of the two isotopes during a reaction or process (Tucker and Wright, 1990). The ^{18}O and ^{13}C ratios in water, bicarbonate and carbonate are related by equilibrium constants (isotope fractionation factors) which are functions of temperature. Thus, the $^{18}O/^{13}C$ variations measured in carbonates are not exactly the same as the original variations in the water, which must be taken into consideration when interpreting results. It is, however, generally assumed that primary lacustrine

carbonates precipitate in equilibrium with lake water and thus are related to the isotopic composition and temperature of the lake water at the time of precipitation (Epstein *et al.*, 1953). The resulting fractionation is mineralogically dependent (Stuiver, 1970; Pearson and Coplen, 1978; Gat, 1995).

The record that is produced from the bulk carbonates will therefore be an average signal representing the lake and its catchment. This may mean that changes in the isotopic signature of the system may be dampened with small-scale shifts being lost. As a result of this the trends that are seen in the record must therefore be very significant.

4.5.7 Biogenic carbonates: The record from the gastropods

The record gained from gastropods is a function of both the species microhabitat and the length of its life cycle. Molluscan carbonate grows incrementally and therefore the results from one shell will be a time-averaged result for the life cycle of the species. This tends to be one year. Knowledge of the gastropod species ecology is therefore essential to the interpretation of the results. Fritz and Poplawski (1974) found that there is a good relationship between the ^{18}O in mollusc shells and lake water during the growing season. Differences between species appear to be related to different growth periods and the temperature of their habitat (e.g. shallow versus deep water).

From a palaeoecological perspective one needs to make the assumption that no evolutionary change has taken place that would have altered the relationship between the gastropod and its environment through time i.e. that its life cycle, habitat and feeding requirements have not modified. If this is the case then knowledge of the modern species can be applied through a core sequence (Goodfriend, 1992). One also must be aware that the point of shell deposition may not be where the species lived and thus the conditions which the shells represent may not be of the core environment, but, elsewhere in the lake system.

Equilibrium fractionation between oxygen isotopes of water and shell carbonate is assumed in studies of land snail shells. In aquatic molluscs, shell carbonate appears to be deposited at or near equilibrium with the water in which the gastropods live (Mook and Vogel, 1968; Fritz and Poplawski, 1974). Gastropod shells are made from aragonite and therefore there is a vital offset between the water and carbonate and also between calcite and aragonite. Tarutani, *et al.* (1969) established this to be 0.6 at 25°C for oxygen isotopes. Thus, aragonite concentrates ^{18}O relative to calcite. Rubinson and Clayton (1969) worked out a fractionation of 1.8+/- 0.2 for carbon values resulting in ^{13}C being enriched in aragonite as compared to calcite. For the Belize investigation vital effects were minimised by analysing only adult specimens of particular species because Curtis *et al.* (1996) determined that mature individuals of *Pygophorus* and *Cochliopina* species secrete their shells near oxygen isotope equilibrium.

There are two main ways in which one can gain isotopic information from gastropods. One is to crush a shell and take a reading from a representative portion of the powder. This will provide an average for the individuals life cycle. Alternatively, measurements can be taken along the growth whorls which provide a much more detailed record of change (e.g. Leng *et al.*, 1998). This requires shells to be quite large so that the growth stages can be distinguished. The shells used in this study were 2 mm – 3 mm and therefore unsuitable for the latter application.

The controls on the stable isotopes in the gastropod shell are more complicated than on bulk carbonates. The ^{13}C of shell carbonate is affected both by the isotopic composition of the dietary carbon (plant matter and inorganic carbonates) and the degree to which this is modified by exchange with atmospheric CO_2 (Leng, 1998). Where variations are low in the carbon record it implies that all the proportions from the different carbon sources have remained constant. Factors affecting shell carbonate ^{13}C values will also influence the ^{18}O values most notably the metabolic rate relative to exchange with the environment (Leng *et al.*, 1998). If metabolic and temperature induced variations can be discounted, the changes must be due to variations in the isotopic composition of the environmental water taken in by the

gastropod (Leng *et al.*, 1998). It is important to have an understanding of the microhabitat changes, which will influence the isotope values recorded in the shells. An example of this is the photosynthetic activity of aquatic plants. In a similar manner to terrestrial plants, aquatic plants preferentially utilise isotopically light carbon which results in ^{13}C enrichment in the immediate vicinity of these plants.

Two species were used in this study: *Cochliopina* sp. and *Pygophorus* sp. These were identified by Alan Covich (February, 1999). These have been successfully used in isotopic studies elsewhere in Central America (Covich and Stuiver; 1974; Curtis *et al.*, 1996; Curtis *et al.*, 1998). Both these species are present in Covich's (1976) study of molluscan species diversity in the Peten, Guatemala. Both *Cochliopina* and *Pygophorus* sp were also used in Curtis *et al.*(1998) study of Lake Peten-Itza, Guatemala and the two species produced very similar isotopic records.

Covich undertook a study of freshwater gastropod assemblages in Albion Island, Belize (Pohl, 1990). In this investigation environmental inferences were made on the basis of the species found at each level. *Cochliopina* sp. is typical of deep, permanent freshwater in Belize and it is also found in the Mexican Yucatan Peninsula. They feed on periphyton and bacteria and live on rocks and dead wood. Not much is known about the water quality tolerances but they need sufficient levels of dissolved oxygen as they are gill bearing prosobranchs (Covich pers. com. February, 1999).

Pyrgophorus sp. is distributed throughout the Caribbean and coastal areas of the Gulf of Mexico. It is typical of permanent, relatively deep lakes (Covich, 1983). Live specimens were found in the littoral zone of Pulltrouser Swamp. There are two forms of this species smooth and spiniose. There is no consensus as to whether this difference represents an ecological variation or is a response to predation (Covich, 1983).

In summary, both gastropod and bulk carbonate measurements were carried out in this investigation. This was because these two sources provide complementary

information to one another. The bulk carbonate provides a general record whereas the signal from the gastropods is specific to their habitat and will therefore be influenced by slightly different factors. The combination of these two will enable a much clearer idea of the lake dynamics to be developed. It will also enable an improved understanding of the inputs into and controls over the bulk carbonate record.

4.5.8 Methodology

A carbonate bomb was used in order to measure the percentage of carbonate in the sediment. This provides information on not only changing inputs to the catchment but also determines whether the material is suitable for stable isotope analysis. 0.7g of dried sediment and a fixed volume of 6N hydrochloric acid were added into the vessel. As the vessel is shaken, the sediment and acid react to produce carbon dioxide. The amount of gas evolved is proportional to the percentage of carbonate in the sediment.

Stable isotope analysis of the bulk carbonate material was carried out at Scottish Universities Environmental Research Centre by Mr Andrew Tait (SUERC) and the author. 1 mg of each sample and standard were weighed and loaded into glass tubes which were sealed with a cap containing a piercable septum. Once all the samples were loaded they were placed into a temperature controlled hot block at 70°C for 30 minutes. This ensured that the samples were at reaction temperature. The carbonate acid injector was then placed into each tube in turn. In the first phase ultra-pure helium was used to purge all the atmospheric gases from the tube, for two minutes. 7 or 8 drops of '103%' phosphoric acid were then added to the tube. This reaction was then left to proceed for at least 8 hours. Once the reaction had finished the tubes were transferred from the carbonate acid injector to the AP2003 Gas Prep Interface. This analysis consisted of a single reference peak followed by four sample peaks from one tube and then a final reference peak. Gas was extracted from the sample tube and was moved through a small room temperature gas chromatograph which separates the CO_2 from any other gas which may be in the tube. The resulting gas

then flowed into an AP2003 triple collector mass spectrometer which measured the 45/44 and 46/44 ratios. The δ value for the CO_2 was then calculated from the ratios of the sample gas peaks and the reference gas peaks.

The calculations are as follows:

45/44 $(^{13}C + {}^{16}O_2) / (^{12}C + {}^{16}O_2)$
46/44 $(^{12}C + {}^{16}O + {}^{18}O) / (^{12}C + {}^{16}O_2)$

$\delta^{13}C = 1.0676\ \delta(45/44) - 0.0338\ \delta^{18}O$
$\delta^{18}O = 1.0010\ \delta(46/44) - 0.0021\ \delta^{13}C$

For the analysis of gastropods, shells were picked out from the sediment and cleaned in distilled water in an ultrasound bath until all the residual sediment had been removed from the shell. These were analysed by Mr Colin Chilcot (Department of Geology and Geophysics, University of Edinburgh) and the author. 0.5-1mg of shell powder was reacted with 100% orthophosphoric acid at 90°C in an automatic carbonate preparation system. The resulting CO_2 was then analysed on a VG Isogas PRISM III mass spectrometer. The standard MAB2B was analysed with each run with the standard deviation being +/- 0.0073 for $\delta^{13}C$ and +/- 0.071 for $\delta^{18}O$. All the measurements were corrected for isobaric interference.

4.6 Chronology

In order that the results of this investigation can be put into a meaningful context, the sediments need to be dated. There are several ways in which this can be done. In this study radiometric methods were used namely radiocarbon and ^{210}Pb dating.

4.6.1 Radiocarbon dating

Radiometric dating techniques are based on the time dependent radioactive decay which unstable isotopes undergo. Radiocarbon dating was one of the earliest

radiometric techniques to be developed (Libby, 1955). ^{14}C is the radioactive isotope of carbon and eventually decays to form the stable element ^{14}N. ^{14}C atoms are rapidly oxidised to carbon dioxide and along with $^{12}CO_2$ become mixed throughout the atmosphere and gets stored in the atmosphere, biosphere and hydrosphere (Lowe and Walker, 1997). The activity of ^{14}C is halved every 5730+/- 40 years (Godwin, 1962), this was a revision of Libby's 1955 estimation of 5568+/- 30 years. However, because a large number of dates had been published using the original estimation an internationally agreed constant has been agreed on. This is 5570 +/- 30 years (Mook, 1986).

The ^{14}C activity of a sample is measured by two methods: conventional radiocarbon dating (which involves the detection and counting of β emissions from ^{14}C atoms over a period of time) and accelerator mass spectrometry (which uses particle accelerators to count the actual number of ^{14}C atoms in the sample). The dates produced in this study have all been produced using the latter methodology, which allows for the more accurate dating of much smaller samples than the conventional method.

4.6.2 Issues of dating in limestone geology

A large proportion of northern Belize is composed of a limestone terrain and thus the key issue in relation to radiocarbon dating is the introduction of ^{14}C deficient carbon into the reservoir of dissolved inorganic carbon in surface and groundwaters (Leyden *et al.*, 1998). When this is incorporated into aquatic primary producers; precipitating marl or the carbonate shells of aquatic organisms, the result is anonymously old radiocarbon ages. This phenomenon is known as the hardwater effect (Deevey and Stuiver, 1964). Terrestrial organic matter is free from this influence because it is in isotopic equilibrium with the atmosphere and is therefore the ideal dating medium. This, however, was sparse in the cores that were collected in this investigation.

A strategy which has been used to overcome the lack of terrestrial organic matter in other studies in Central America, is the dating of gastropod shells. Curtis *et al.*

(1996) dated both terrestrial wood and aquatic gastropod species from Punta Laguna. It was found that the dates obtained from the shells were consistently older by 1200-1300 years. This correction factor was then applied to the other gastropod dates because it was believed to represent the hardwater effect in the system. Hodell *et al.* (1995) found dates obtained from aquatic gastropods from Lake Chichancanab, were 1200 years older than those obtained from terrestrial organic material. Hodell *et al.* (1991) investigated Lake Miragoane, Haiti. The chronology for this sequence was based on dates from ostracod shells and two from organic carbon. One level had both an ostracod and terrestrial wood date. The difference between these two was 1025 years. It was assumed from this that the hardwater error was constant throughout the core and a correction of 1000 years was applied to the ostracod dates obtained.

There are two strategies that have been employed in the literature with regard to the correction factor applied to gastropod dates:

1. Paired dates (i.e. terrestrial organic matter and a gastropod from the same level) can be obtained and the difference between the two dates can be regarded as the hardwater error
2. Where it is not possible for dates to be obtained from both media at the same depth, results from each can be plotted separately and the difference between the two gradients can then be used as the correction factor to be applied to the gastropod dates.

From the diatom records, which have been produced from Belize, the species do not show any significant shifts with regard to pH or other water chemistry variables suggesting that the hardwater error is likely to have been constant through time.

4.6.3 Methodology

When each core was opened any material which was thought to be suitable for radiocarbon dating, was removed and placed in a darkened petri dish. All material was stored in the cold store in the Department of Geography and the British

Geological Survey, Edinburgh. Once samples had been approved for dating they were brought to the NERC Radiocarbon Laboratory and prepared by Dr Charlotte Bryant and colleagues. The reference number for the dates used in this investigation is: 761.1298.

The pre-treatment of the samples before dating depended on the type of material that was submitted. For plant macrofossils, any carbonaceous sediment was removed by soaking the samples in 2M Hydrochloric acid until the pH remained less than 7. The samples were then rinsed in distilled water and digested in a further aliquot of 2M Hydrochloric acid at $80^{O}C$ for 8 hours. Samples were then rinsed with distilled water and dried to a constant weight. A pestle and mortar was used to homogenise the material. The total carbon in a known weight of the pre-treated sample was recovered as CO_2 by heating with CuO in a sealed quartz tube. The gas was converted to graphite by Fe/Zn reduction (C.Bryant pers com, 2001).

Gastropod samples were soaked in hot distilled water to remove any sediment from the shells. The outer 20% by weight of the shells was removed by controlled hydrolysis with dilute Hydrochloric acid. The samples were then rinsed in distilled water, dried and homogenised. A known weight of pre-treated sample was hydrolysed to CO_2 using 85% orthophosphoric acid at $25^{o}C$. The gas was converted to graphite by Fe/Zn reduction (C.Bryant pers.com, 2001).

4.6.4 Lead 210 dating

Radiocarbon dating can be used over the last 50,000 years (Lowe and Walker, 1997). The fine temporal resolution examination of recent sediments can be achieved through ^{210}Pb dating which can be used over the last 150 years to date events (with a half life of 22.26 years). The radioactive decay of radon gas (^{222}Rn) which is part of the U-series decay chain produces a series of daughter nuclides, one of which is ^{210}Pb (Lowe and Walker, 1997). This unstable isotope is removed from the atmosphere and accumulates in lacustrine, terrestrial and marine environments where it decays to the stable ^{206}Pb. The ratio of ^{210}Pb to ^{206}Pb can then be measured and assuming that

the atmospheric flux of ^{210}Pb has remained constant, the time elapsed since the lead was deposited in the sequence can be established (Olsson, 1986). This methodology will therefore also allow the rate of sediment accumulation to be estimated. The main problem is that most sediment contains a small amount of ^{210}Pb derived from the decay of uranium or its daughters. This is known as the 'supported' ^{210}Pb and must therefore be calculated and subtracted from the 'unsupported' ^{210}Pb which is produced in the atmosphere (Lowe and Walker, 1997). The 'supported' component is calculated by measuring the ^{226}Ra activity. In a system that is accumulating sediment at a uniform rate the activity of 'unsupported' ^{210}Pb will decrease exponentially with depth.

There are two key methods for the calculation of sediment accumulation rates: the Constant Rate of Supply (CRS) model and the Constant Initial Concentration (CIC) model (Goldberg, 1963). The difference between the models is the assumptions that they make. The CRS model assumes that unsupported ^{210}Pb flux is constant but that the initial ^{210}Pb concentration in the sediment is variable, as is the influx of sediment. The CIC model assumes that all these variables are constant.

As an independent means for testing the ^{210}Pb age chronology, man-made radionuclides can be analysed (Eades *et al.*, 1998). Due to the testing of nuclear weapons in the 1950s and 1960s, artificial radionuclides were released into the atmosphere. ^{137}Cs reached its peak concentration in 1963 (Bonnett and Cambrey, 1991). A second peak is also found in 1986 due to the fallout associated with the Chernobyl disaster.

Biological and physical activities which occur near the sediment-water interface result in the redistribution of sediments. Three major processes govern the concentration of radioactive nuclides within a sediment sequence: radioactive decay, sedimentation and mixing. The measurement of artificial radionuclides provides information on sediment accumulation rates. The key problem with this is that postdepositional mixing, erosion and redeposition processes destroy the original delivery pattern to the sediments (Krishnaswami and Lal, 1979).

Davies (2000) successfully demonstrated the use of ^{210}Pb as a chronological tool in Lago de Zirahuén, Mexico. The calculated depositional flux for this basin was 48 Bq $m^{-2}yr^{-1}$ which is much lower than the global average of 185 Bq $m^{-2}yr^{-1}$ (Appleby and Oldfield, 1983). This implies that there maybe regional variations in the global flux of ^{210}Pb (Davies, 2000). ^{210}Pb has also been successfully used in Lake Miragoane, Haiti (Brenner and Binford, 1988; Hodell *et al.*, 1991). This thesis found that the ^{210}Pb fallout rate was very low (0.09 pCi $cm^{-2}yr^{-1}$ as compared to a global average of 0.5 pCi cm^{-2} yr^{-1}). The reasons for this discrepancy are not clear but it could be due to loss of sediments from erosional zones, the result of upward migration and solubilisation of sedimentary ^{210}Pb under conditions of deepwater anoxia or low rates of ^{222}Rn flow from the sea surface and local soils (Brenner and Binford, 1988).

4.6.5 Methodology

4g of dry sediment from a 1cm slice of material was ground with a pestle and mortar and weighed into petri dishes. The petri dishes were then sealed with an epoxy resin to stop the radon diffusing. Samples were then left for 3 weeks to attain radioactive equilibrium. The activity of the radionuclides was determined by gamma spectroscopy. Mrs. A. Stewart and Dr. A. MacKenzie at the Scottish Universities Environmental Research Centre at East Kilbride and the author carried out the analyses.

4.7 Other methodologies employed

Dr Malcolm Murray carried out the following analyses on a parallel investigation to this one funded by the Leverhulme Trust (F/158/BQ). This information has been used to supplement the methodologies already described.

4.7.1 Available phosphorus

Studies have shown that one of the environmental responses to population growth in the Peten was an increase in the delivery rate of phosphorus to lakes (Brenner, 1978; Deevey *et al.*, 1979; Vaughan, 1979). Brenner (1983) found that total phosphorus levels in the catchment soils around Lake Quexil were extremely similar to those found in the lake sediments. This suggests that soil movement is the principal means of nutrient transfer. Activities by humans in the catchment would have released phosphorus to soils where it would have been locked into insoluble compounds and removed by erosion (Deevey and Rice, 1980). Work in Peten has also shown that phosphorus is much more concentrated in surface soils than lower horizons and at the bottom of slopes (Brenner, 1983). Changes in phosphorus levels can therefore be regarded as a cultural signal.

Evidence for the mobilisation and deposition of phosphorus is very important as it is essential to support ecosystem dynamics (Brenner, 1983). Deevey *et al.* (1979) believe that phosphorus is an element which is likely to have become deficient in the Mayan environment because soluble phosphorus is immobilised by calcium in a limestone terrain and is not replaced by the atmosphere. Available phosphorus is critical if most of the phosphorus is transferred to the sediments by runoff (Deevey *et al.*, 1979).

Available phosphorus levels in this investigation were determined using a HACH DR2000 portable spectrophotometer. The colour of the solution produced by this methodology is proportional to the amount of phosphorus in the sample.

4.7.2 Magnetic susceptibility

The measurement of magnetic susceptibility is generally considered to be a proxy for catchment disturbance (Thompson, 1984). In limestone terrain, the presence of a strong magnetic susceptibility signal cannot be guaranteed, but changes may indicate inputs of clay or iron rich soils from the slopes.

One of the most common applications of this technique has been to use the magnetic signal to identify times of increased catchment erosion. This is picked up because topsoil has a greater magnetic signal than subsoil. Where clear peaks and troughs are exhibited in a record this method can be used to cross-reference cores from the same region. O'Hara *et al.* (1993) successfully used this technique as an indicator of human induced catchment disturbance in Lake Patzcuaro, Mexico.

These measurements were taken with Bartington Instruments MS1 and MS2 meters which were connected to 80mm or 125mm MS2C loop sensors. Mass specific susceptibility was measured using a Bartington MS2B dual frequency sensor. Samples were dried at 40°C and placed into $10cm^3$ pots and then weighed.

4.7.3 Particle size analysis

Binford (1983) proposed that particle size changes down core could be used as an index of human activity in the catchment. A drop in mean particle size is thought to represent times of increased disturbance and can be used to cross-correlate cores from a region. Changes in mean particle size can also occur by natural changes such as climatic or hydrologic changes to the basin. The usefulness of this technique does depend on the geology of the area. Pohl *et al.* (1990) undertook particle size analysis in Albion Island, Belize. They did not come up with any meaningful conclusions due to the flocculation of clay particles and the high content of gypsum in the sediment.

Analyses were undertaken using a Beckman Coulter LS230 laser diffraction particle analyser. Samples were pre-treated with hydrochloric acid (to remove the carbonates) and hydrogen peroxide (to remove the organic matter). The results therefore reflect the non-carbonate mineral fraction. Details of this methodology and the problems associated with particle-size analysis in carbonate sediments are discussed in Murray (in press).

4.7.4 X-ray diffraction (XRD)

In order to gain an idea of the bulk mineralogy XRD was undertaken using a Phillips PW1800 instrument. Knowledge gained from this technique is very helpful to the interpretation of the stable isotope record. Fractionation of aragonite, dolomite and calcite is different and therefore if the system is a mixture of these or changes from one mineral to another this will affect the interpretation of the isotope results. Information from XRD allows one to make inferences about the sediment sources to the systems and the weathering regimes to which the system has been subject to.

XRD analyses were undertaken in the Department of Geology and Geophysics, University of Edinburgh by Dr Malcolm Murray, Mr Geoff Angell and the author. A mixture of dried sediment and acetone was dropped onto a glass slide to create a thin covering which could then be analysed. For samples with a high clay content, the same analysis was repeated on just the clay fraction. This was separated out by producing a suspension in water and sampling from the liquid after sediment settling had occurred.

4.7.5 Loss on ignition

This technique is used to determine the amount of organic matter present in a sample. 1-2g of sediment was weighed out and placed in a furnace for two hours at 500-550°C to ensure that all the organic carbon in the sample was completely oxidised. This method will provide another proxy for environmental change in the system which will be valuable for corroborating with the other records produced.

4.7.6 Carbon and nitrogen analysis

The ratio of carbon to nitrogen is used to determine changes in the sources of organic matter to lakes. This is possible because the signatures from algae and terrestrial organic matter are distinctive (Meyers, 1994). This method will provide a valuable additional information to the $\delta^{13}C$ record.

Carbon and Nitrogen analysis was undertaken using a Carlo-Erba NA 1500 Elemental Analyser in the Department of Geology and Geophysics, University of Edinburgh. For this method 40mg of air-dried and ground samples of sediment were used. This amount is larger than is normally required but this ensured that reproducible nitrogen values were obtained. The methodology followed that employed by Nieuwenhuize *et al.* (1994).

4.8 Conclusions

This chapter has provided key background information on methodologies employed in this investigation. This not only highlights the suitability of these methodologies to answering the main questions behind this project but also aids in the understanding of the results gained. The statistical techniques which have been employed in this study enable the rigorous classification of the data sets providing the basis for environmental interpretation. The trends which have been delimited in the data sets will be put into context by the chronology created by ^{14}C and ^{210}Pb dating. This is vital to ensure that the activities of humans in the areas studied can be assessed in terms of the environmental records collected.

This project comprises two main components: the climatic and the human signal. The techniques which have been employed will tease out both of these, allowing a greater insight into the lake systems under investigation. Oxygen isotopes will provide the main climate signal. Phosphorus, particle size analysis and magnetic susceptibility will provide an indication of human activity. The diatom record is one of general environmental change which will be influenced by a number of different factors. XRD, carbon:nitrogen ratios, LOI and carbon isotopes will provide a suite of information which will also improve understanding of the lake dynamics.

The key proxy which has not been mentioned is pollen. A preliminary record for the long core at Hillbank, New River Lagoon has been produced by Ms Viveca Persson and Professor Steve Blackmore while at the Natural History Museum, London

(present address for SB is the Royal Botanic Gardens, Edinburgh). This record is very coarse with many of the species being unidentified. This limits the interpretations that can be made but it does help to provide some idea of vegetation changes through time.

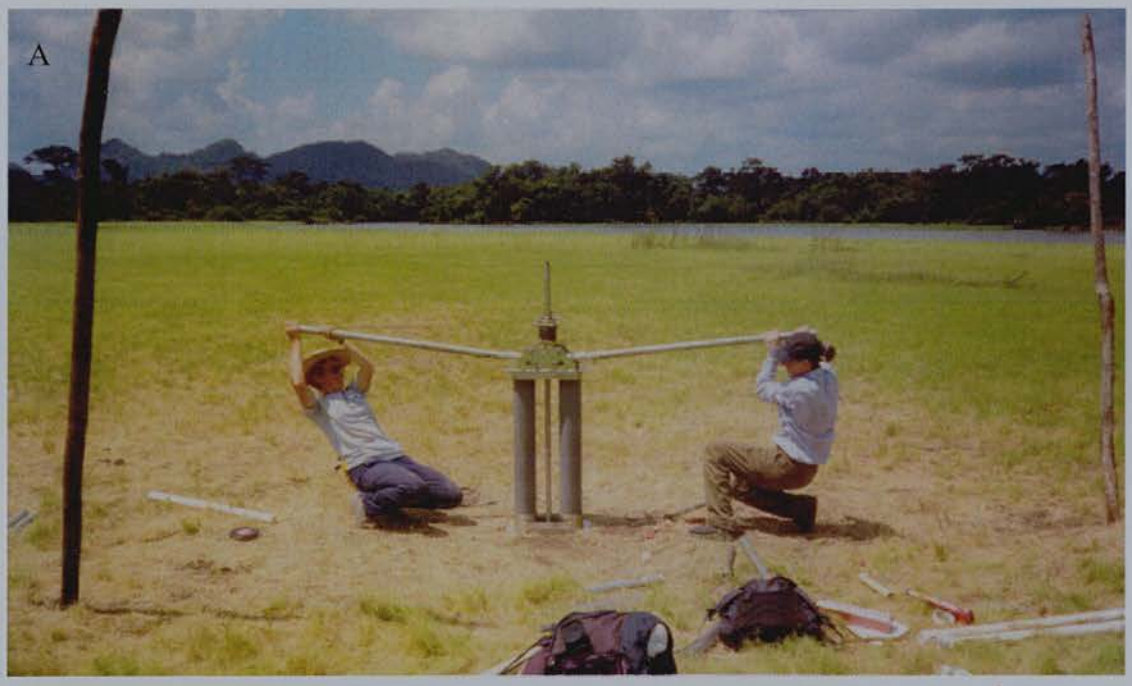


Figure 4.1

A. Percussion coring at Aguacaliente Swamp

B. Livingstone coring at Hillbank

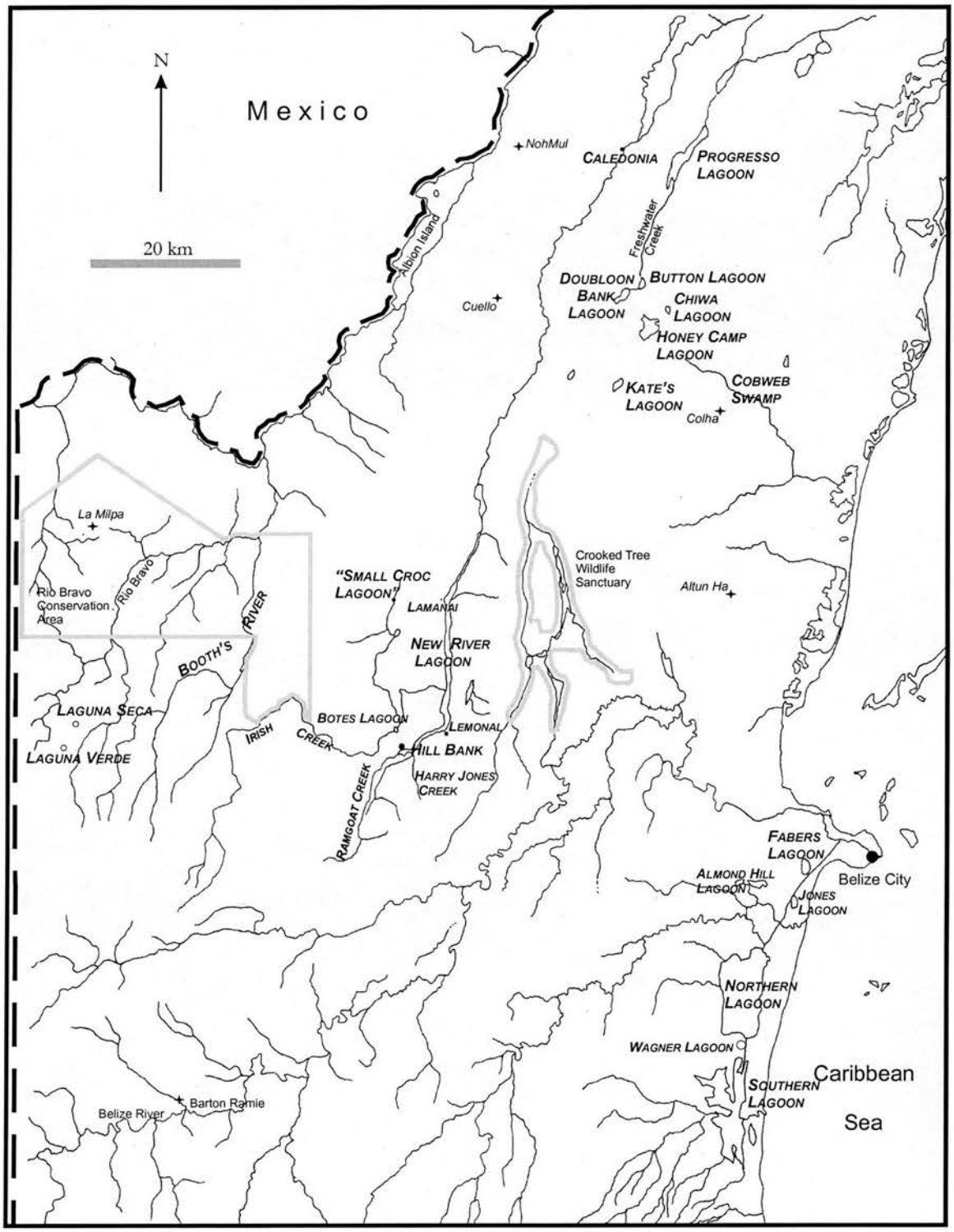


Figure 4.2 Location map of northern Belize showing the places referred to in this thesis.

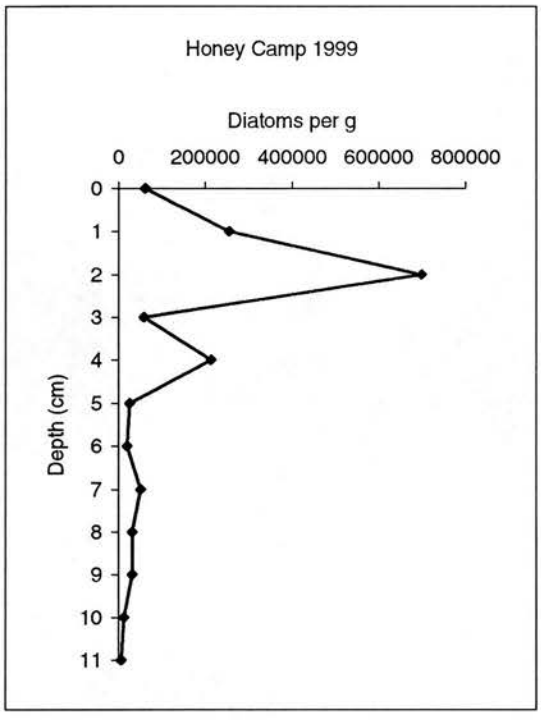


Figure 4.3 Diatom concentration in Honey Camp Lagoon 1999

Pink:
Weighted
index

Green:
Square
weighted
index

Blue:
DDI
index

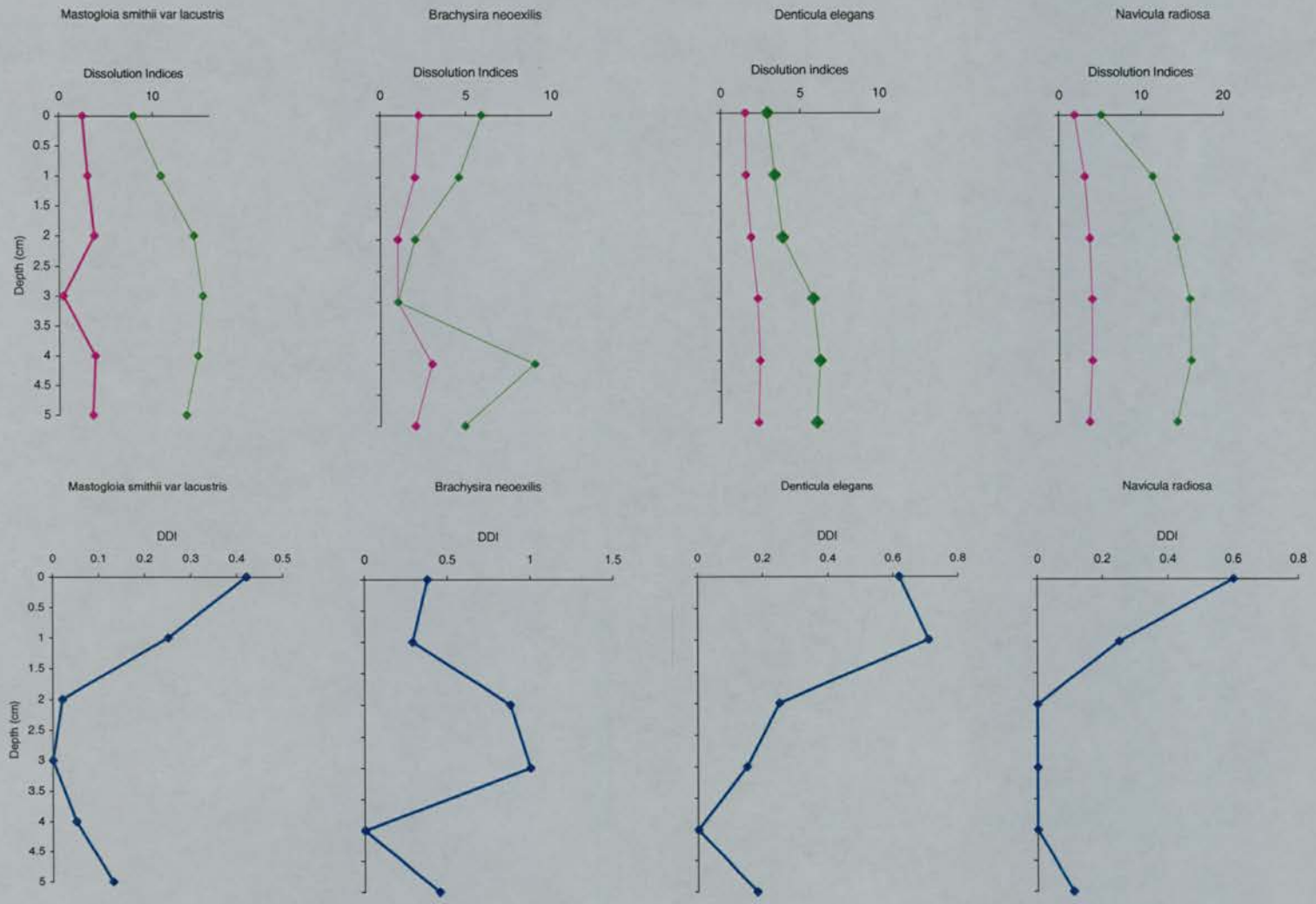


Figure
4.4

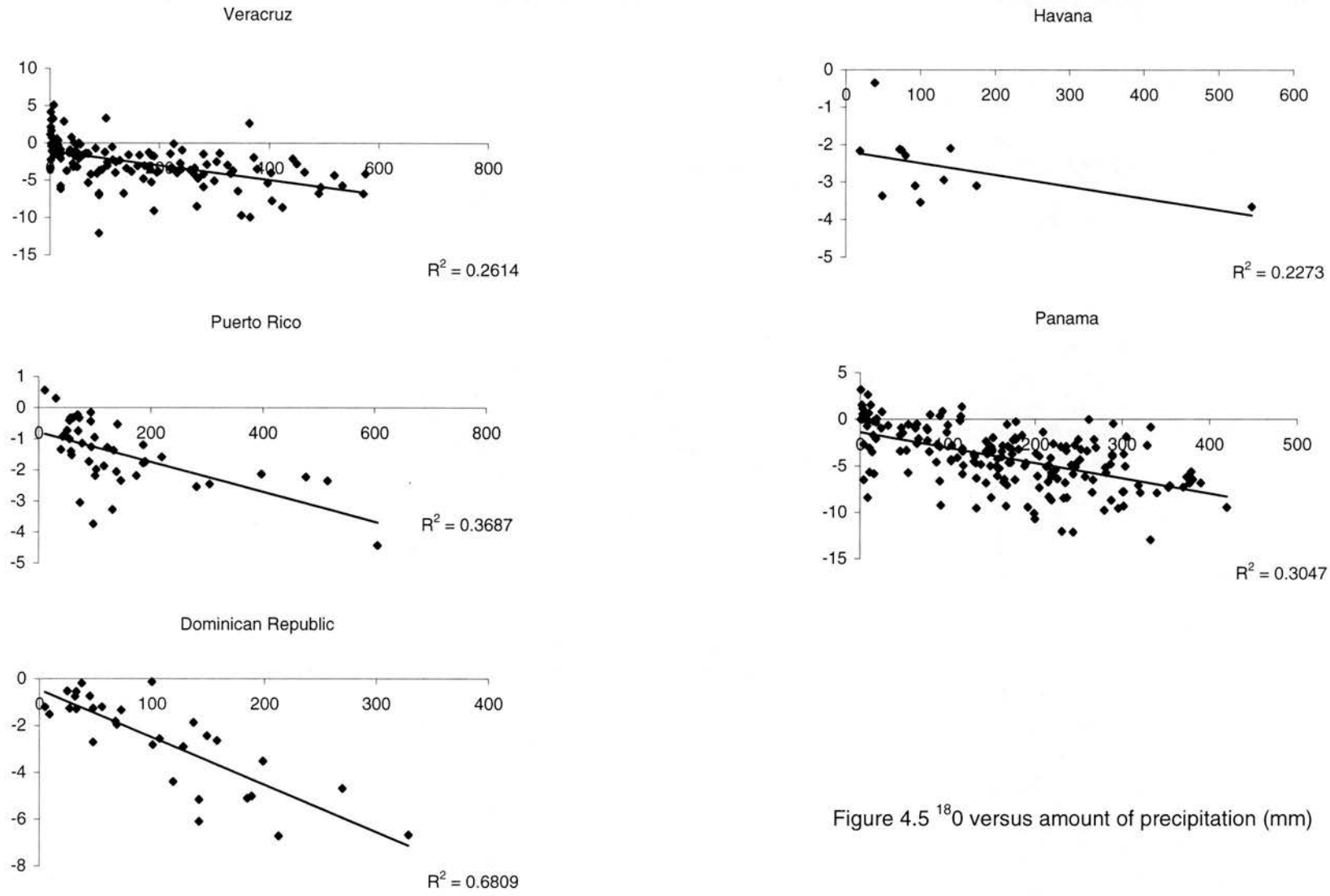


Figure 4.5 $^{18}0$ versus amount of precipitation (mm)

Chapter Five - Results: The Modern Environment

5.1 Rationale

One of the principal methodologies employed in this project to investigate the changes that have occurred in the environments of Belize through time was diatom analysis. This is the first time that this tool has been applied in Belize. In the previous chapter it was explained that in order to develop a meaningful interpretation of fossil records a knowledge of the modern diatom flora is essential. This chapter provides the interpretation of those results. In the final part of this chapter the results from the modern isotope survey will be discussed. Figure 4.1 shows the location of the water bodies sampled. The two sites in the south of Belize (Monkey Tail River and Aguacaliente Swamp) are shown on Figure 1.1. A number of different samples were taken from Hillbank and Lamanai. These are shown in more detail in Figures 5.2 and 5.3.

5.2 Water chemistry

Water chemistry data were collected over three years as part of the author's MRes and PhD studies from a variety of sites in Belize. The methodology employed has been described in Chapter 4. The information in this chapter provides an indication of quantitative differences between sites. There are issues with the data set which need to be considered before interpretations are made. The data were collected from 1998-2000 at approximately the same time of year. It is not known however how conditions varied seasonally through this time frame, but values from the same lakes over the different years are comparable suggesting that the data are reliable. The number of water chemistry variables measured at the sites is not consistent because the water samples collected in the year 2000 were stolen at the end of the field season. This means that variables cannot be compared throughout the whole data set. The accuracy of the field equipment used has not been quantified. The same equipment was used throughout and therefore the results can be considered to be comparable within themselves. Both Honey Camp and Kates Lagoon have been measured for a variety of water chemistry variables in the past (Brenner pers. com.

(data from 1985); Jacob, 1992). These results fall within the same range as those collected in this study, which is encouraging in terms of the validity of this data set. The results are listed in Figure 5.4.

5.2.1 Discussion

The triangular diagrams (Figure 5.5) contain cation and anion data for the sites visited on the 1999 field season. Water chemistry measurements from the other sites visited did not contain the full complement of variables. Although limited, the 1999 data set provides an indication of the general characteristics of water bodies in Belize.

The sites fall into two clear groups and a group of outliers. The groups are:

1. Calcium-Sulphate dominated: Aguacaliente Swamp, Lamanai, Booth River and Small Croc Lagoon. The pH range for these sites is 6.82-8.1. The conductivity range is 0.6-1.63 $mScm^{-1}$.
2. Sodium-Chloride dominated: Honey Camp Lagoon, Progresso Lagoon, Fabers Lagoon, Jones Lagoon, Northern Lagoon, Southern Lagoon and Wagner Lagoon. The pH range for these sites is 7.92-8.35. The conductivity range is 1.6-23.34 $mScm^{-1}$.
3. Calcium-Total Carbonate dominated: Kates Lagoon. This site has a pH of 7.76 and a conductivity of 0.27 $mScm^{-1}$.
4. Magnesium-Total Carbonate dominated: Chiwa Lagoon. This site has a pH of 7.21 and a conductivity of 0.43 $mScm^{-1}$.
5. Calcium-Sulphate/Total Carbonate dominated: Crooked Tree Lagoon. This site has a pH of 8.06 and a conductivity of 0.6 $mScm^{-1}$.

From this information a number of key points can be made. The characteristics of the sites that fall into group 1 concur with Eugster and Hardie's (1970) second evolutionary pathway whereby the systems are enriched in alkaline earths and have low levels of carbonates. The second group in this study are further along the pathway falling in category IIB i.e. their water chemistry is more evolved. This

suggests that there is continuation of water chemistry throughout the lake bodies that have been studied. The three outlying sites (3-5) are all rich in total carbonates which suggests that these are true freshwater systems. Both the pH and conductivity ranges for group 2 are higher than group 1, which is a further indication that these are evolved systems.

The two sites of principal interest to this investigation are Honey Camp Lagoon and the New River Lagoon. The water chemistry for the latter site can be represented by Lamanai. These two sites fall into separate groups and represent the two main types of lakes that have been studied in Belize. This difference is not surprising as the New River Lagoon is a large, open system and Honey Camp Lagoon is much smaller, closed system. This helps to explain why its water chemistry has evolved along the brine pathway.

If one excludes the coastal sites (Almond Hill, Northern Lagoon, Southern Lagoon, Progresso Lagoon, Wagner Lagoon, Fabers Lagoon and Jones Lagoon) the range of conductivity between all the sites studied (Figure 5.4) is fairly low between 0.23-2.19 $mScm^{-1}$. The pH range for all the sites is between 6.61-8.76 which again is not high. The sites that were measured for phosphates and nitrates do not show any sign of nutrient enrichment (Figure 5.4).

5.3 Modern diatoms

Diatom samples were collected in conjunction with the water chemistry variables. The methodology involved has been described in Chapter 4. Through studying the modern diatom flora knowledge of species associations and preferences can be established. This will enable a better understanding of both the lake systems of Belize and in particular, improved interpretation of the New River Lagoon fossil record. This work is of particular value due to the paucity of knowledge concerning both the diatom flora of Belize and the lake systems. The data has been analysed through Canoco, which is an ordination programme (see Chapter 4). The main aim of this section is to present the results and preliminary analysis of this work. All the

diatom species mentioned are pictured in appendix 2. The total list of the diatom species and their abundance found in the modern samples can be found in appendix 3. The list of diatom samples taken from each water chemistry site can be found in appendix 4. Of particular note are the samples which did not preserve diatoms. These were mainly restricted to plankton and sodium chloride dominated samples.

5.3.1 The modern data set

Modern samples were collected from a number of water bodies over the period 1998-2000 (in the Spring) from a variety of habitats including surface sediments, plankton, reeds, cutting grass and aquatic algae. These were preserved in alcohol and brought back to the UK where they were digested in Hydrochloric acid and Hydrogen Peroxide (Battarbee, 1986). Permanent slides were made using the mountant naphrax and the samples were counted using an Olympus BX50 microscope at x1000 resolution. This data set is made up of the 31 sites visited and the species counts (up to 400 valves) from the 73 samples in total. A further 25 samples were collected but did not contain diatoms. Two data sets were created and analysed. The first comprises all the species that were encountered at each site. In order to ensure that the associations between the sites, created in the canonical analyses, were firm and not just a function of rare species, a second data set was created which contained only the species that reached 2% or more of a population. These will be referred to as the full and dominant data sets respectively.

Figures 5.6 and 5.7 show the first two axes created in DCA. The eigenvalues for the two axes in the full data set are high at 0.7973 and 0.6008. The closeness of these two values suggests that both axes are important in the explanation of the species/site scores. The eigenvalues for the dominant data set are 0.7916 and 0.606. The similarity between the eigenvalues for the two data sets suggests that the removal of the rare species does not strongly influence the amount of variance that the axes explain. This suggests that the rare species are not central to the associations seen in these data sets. The groups formed in the two data sets are also extremely similar. It is clear from the graphs that the sites and species form a gradient along the first axis.

This must represent a significant environmental gradient because the axis is very long.

Using the dominant data set, the sites form five groups: (Figure 5.7)

1. Southern Lagoon (sed) (circle)
2. Rio Bravo (sed), Monkey Tail River (stones), Aguacaliente Swamp (pla) and Irish Creek (sed) (filled circle).
3. Progresso Lagoon (sed) and Almond Hill (triangle).
4. Rio Bravo (pla), Monkey Tail River (sed), Irish Creek (pla), Lemonal Creek (pla), Chiwa Lagoon (sed) and Harry Jones Creek (sed) (filled triangle).
5. The fifth group (square) and this contains most of the sites sampled including Crooked Tree Lagoon, Booth River, Kates Lagoon, Lamanai and Honey Camp Lagoon.

In the full data set, groups 1 and 2 were not distinct from one another. The removal of the rarer species has therefore emphasised the difference of Southern Lagoon. This is not unexpected as this site has a conductivity of 23.34 $mScm^{-1}$ which is significantly higher than any of the other sites in group 2. The species that are associated with Southern Lagoon are: *Navicula florinae*, *Cocconeis placentula* var *eugylpta* and *Diploneis parma* (circle). These can all be found in brackish conditions, especially *Navicula florinae* which is a coastal species.

There is only one species that is common to the four sites in group 2 (filled circle): *Navicula radiosa* var *tenella*. Other common species for these sites include: *Cymbella microcephala*, *Nitzschia palea*, *Gyrosigma acuminatum*, *Navicula cuspidata* and *Schistauron crucicula*. These species can all be found in swamp or riverine environments and have wide ranging tolerances to chemical conditions. The sites in this group are in rivers and in southern Belize. These present quite different habitats for diatoms than found in the lake environments of north Belize. The lack of species consensus for these sites is not surprising because the river environment provides a great deal more opportunity for species specialisation than a lake due to

an increased number of habitats and constant changes to the ecosystems e.g. to the water flow.

The species that separate group 3 (triangle) are low in their occurrence and include an unidentified species and *Achnanthes minutissima*. The latter species is found in epiphytic habitats, in well-aerated waters and can tolerate concentrated waters (Gasse, 1996). The first species could not be identified because it contains no distinguishing marking which suggests that it is highly dissolved. This suggests that this environment does not present optimum conditions for diatoms. The site Almond Hill (surface mud) which is the outlier to this group. This is because this site has significantly higher sulphate values than any of the other sites sampled (Figure 5.4).

The species that are common to group 4 include (filled triangle): *Brachysira neoexilis*, *Brachysira neoexilis* var small, *Brachysira neoexilis* var capitate, *Encyonema carina*, *Nitzschia amphibia* and *Nitzschia gracilis*. Monkey Tail (sed) is dominated by *Cymbella mesiana*. These species can all be found in lakes and rivers often in the littoral zone. They are fairly widespread in their distribution. Samples that are found within this group are in sites that have already been mentioned in other groups. This is because different habitats were sampled and these must contain sufficiently different species assemblages to separate samples from the same system. Rio Bravo, Monkey Tail, Chiwa and Irish Creek are the sites where this is apparent. This is likely to be because these are (apart from Chiwa) river sites and therefore have a great diversity of ecological niches.

The fact that most of the sites sampled occur in group 5 (square) suggests that they must share a number of key characteristics in terms of both the chemical and physical environment. The common species to these sites are: *Denticula elegans*, *Mastogloia smithii* var. *lacustris*, *Gomphonema gracile*, *Brachysira neoexilis* var. large and *Achnanthes minutissima*.

The key gradient in this data set is along axis one. Through looking at the water chemistry of the sites which fall into groups 1-5 it is apparent that the axis is

representing the evolution from calcium-sulphate dominated systems to sodium-chloride dominated systems or pathway II to IIB according to Eugester and Hardie (1970). One would expect Southern Lagoon to be at the other end of the axis as it is in the same chemical group as Progresso Lagoon. This lagoon has however got extremely high conductivity values and is the most chemically evolved lake that was studied. This suggests that the diatom species present in this lake are quite different to those in the rest of the group and therefore it is quite separate on the graph (Figure 5.7). Most of the sites sampled were present in group 5. The most detailed water chemistry data is only available for the sites sampled in 1999. The 1999 sites, as explained earlier, could also be categorised through pH and conductivity. In order to determine whether the sites that fall into group 5 form a chemical group their pH and conductivity values were analysed:

Table 5.1

Site	pH	Conductivity $mScm^{-1}$
Kates Lagoon (x)	7.76-8.29	0.23
Chiwa Lagoon (x)	7.21	0.43
Crooked Tree	8.06	0.6
Booth River	6.82	0.92
Lamanai	7.29	1.07
Hillbank	7.88-8.44	1.07-1.29
Outpost	8.06	0.91
Monkey Tail (x)	7.55	2
Botes Lagoon	6.61	0.64
Doubloon Lagoon	8.52	1.48
Cobweb Swamp	7.26	0.77
Laguna Seca	7.77	0.32
Laguna Verde	8.65	0.45
Honey Camp Lagoon (x)	8.08	1.6

(x) denotes the sites where not all of the diatom samples collected, from that area, fell into group 5.

According to the 1999 water chemistry data set Booth River, Lamanai, Hillbank and Outpost belonged to the calcium-sulphate group. Cobweb Swamp and Laguna Seca both fit into the pH and conductivity range for the calcium-sulphate group. Botes, Doubloon, Laguna Verde and Monkey Tail appear to be intermediate forms between the calcium-sulphate and the sodium chloride systems. Honey Camp Lagoon is a

sodium-chloride dominated system. It is therefore apparent that the sites in group 5 represent a range of water chemistries but the diatom populations are obviously sufficiently similar to bring the sites together. This suggests that the ecological tolerances of the diatom species found are fairly wide.

The data set which has been analysed is quite large and in order that all the differences and associations can be fully explored between sites and species it is important to create subsets of this main data set. In the first instance the dominant main data set was separated by habitat creating Figure 5.8 in order to determine whether this variable is influential in creating groups within the data set. The sediment sites are represented by diamonds, filled diamonds are epiphytic and crosses are plankton samples.

It is apparent that the sediment and plankton samples are most clearly associated with the environmental gradient represented by axis one as they are stretched out to a greater degree along this axis than the epiphyte sites. The sediment and plankton samples make up groups 2 and 4 and some of group 5 in Figure 5.7. These include sites that are generally in the calcium-sulphate dominated chemistry rather than the more evolved sodium-chloride systems. Groups 2 and 4 are also all either creeks, rivers or swamps. This suggests that in order for a plankton flora to flourish a combination of both chemical and physical factors are needed.

5.3.2 The role of water chemistry

In order to develop a clearer idea of the role of water chemistry the diatom samples from the sites sampled for water chemistry in 1999 were analysed. Not all of these sites preserved diatoms but this data set enables a more specific understanding to be gained concerning the relationship of diatom floras and water chemistry. Figure 5.9 shows the sites. This highlights a clear separation of Southern Lagoon (filled circle), Aguacaliente (circle), Progresso (triangle) and Chiwa Lagoons (filled triangle). The species that differentiate those sites are highlighted on Figure 5.10 using the same symbols.

The species that differentiate these sites are:

1. Southern Lagoon: *Achnanthes exigua*, *Cocconeis placentula* var. *euglypta*, *Navicula florinae* and *Fragilaria brevistriata*.
2. Aguacaliente Swamp: *Schistauron crucicula*, *Nitzschia palea* and *Achnanthes minutissima*.
3. Progresso Lagoon: *Fragilaria fasciculata*, *Denticula elegans* and *Nitzschia amphibia*.
4. Chiwa Lagoon: *Brachysira neoexilis* var. small, *Aulacoseira granulata* and *Diploneis ovalis*.

The clustering of the sites does not exactly match the water chemistry groupings highlighted in section 5.3. Aguacaliente, Booth River and Lamanai were all in the same water chemistry group (calcium-sulphate dominated) but the sites did not form a coherent group in the CCA analysis. This highlights that the diatom flora is affected by factors other than water chemistry such as habitat availability. This therefore emphasises the complexity of interpreting the factors that result in particular associations of diatom species.

A CCA was also carried out to determine the influence that the specific water chemistry variables had on the site associations seen in the 1999 sites. Figure 5.11 is the biplot of the water chemistry and site data for this reduced data set. Although the eigenvalues for the analysis were high at 0.868 for axis one and 0.814 for axis two the water chemistry arrows are not long. This suggests that there may be other factors (that have not been measured) that contribute to the distribution of the sites. Sodium, Potassium, Chloride and conductivity are all very closely related. Other important variables are calcium and sulphate. These two groups of water chemistry variables match the two groups of lake-type highlighted in the 1999 water chemistry study namely calcium-sulphate and sodium-chloride dominated.

5.3.3 Reconstructed conductivity

The following table shows the conductivity optima for the key diatom species found in the modern data set. These values are the weighted average based on the three sites where the species predominate. For the purposes of comparison the values reconstructed by Reed (1998a) are shown.

Table 5.2

Species	Conductivity $mScm^{-1}$ Belize	Conductivity $mScm^{-1}$ Spain (Reed, 1998a)
Mastogloia smithii var. lacustris	0.61	6.17 (3.37-11.33)
Denticula elegans	0.98	2.65 (1.63-4.3)
Encyonema carina	0.67	/
Achnanthes minutissima	2.80	1.88 (0.87-4.09)
Brachysira neoexilis	1.23	1.38 (0.42-4.6)

The values seen in Belize are much more similar to the lower end of the tolerance levels found in Spain. This is likely to be a function of the sampling strategy employed in the respective studies. The implications of this are explored in Chapters 6 and 7.

5.4 The New River Lagoon data set

In order to gain a greater understanding of the New River Lagoon the samples from this area were analysed separately from the main data set. The axes of this reduced data set explain less variance than in the full data set with the first axis having an eigenvalue of 0.5048 and the second 0.2908. The axes are much shorter than in the main data set. This is not surprising because one would expect there to be less variability within one lagoon than between many lagoons. The sites fall into three groups, which relate to the habitat from which they were sampled (Figures 5.12).

The most coherent group of sites are those from epiphytic habitats (filled diamond). There are two outlying sites which are sediment samples from Lamanai and

Hillbank. Both these sites were surrounded by the same mix of vegetation types, which were not present at the same level of abundance in the other sites. This highlights the direct influence of specific habitats on diatom populations.

The sediment samples (diamond) do not form such a coherent group with there being a slight division between the samples from the main lagoon body and those from the side creeks of the New River Lagoon. This highlights the sensitivity of the New River Lagoon flora to slight changes in habitat. The plankton samples are the crosses. These also do not form a coherent group. This is not surprising because all the samples were taken from fairly near the lagoon edge and not in open water. This decreases the possibility of the flora being composed of true planktonic species and increases the risk of 'contamination' from other habitats. Care needs to be taken with this interpretation because the sampling sites were from shallow water and therefore may not even support a true plankton. Although habitats could not be so readily distinguished in the main data set it is apparent that on a more local scale this is an important factor in differentiating between diatom populations. Specific diatom species have therefore been isolated as indicative of a particular environments in Belize (Figure 5.13).

Table 5.3

Habitat	Species
Epiphyte	*Achnanthes minutissima* *Brachysira neoexilis* var. large *Gomphonema gracile* ***Mastogloia smithii* var. *lacustris***
Sediment (outliers)	*Mastogloia elliptica* var. *dansei* *Fragilaria construens* *Nitzschia amphibia* var. *rostrata*
Sediment (Main Lagoon body)	*Achnanthes exigua* *Brachysira neoexilis* var. capitate *Brachysira neoexilis* var. large capitate *Denticula elegans* ***Encyonema carina*** *Navicula radiosa* *Nitzschia amphibia*
Sediment (Side Streams)	*Brachysira neoexilis* var. small *Gomphonema intricatum* var. *vibrio*
Plankton	*Brachysira neoexilis* *Fragilaria ulna* *Navicula radiosa* var. *tenella* *Nitzschia palea* *Nitzschia gracilis*

The two species highlighted in bold are very common in a whole range of sites.

In general terms these habitat categorisations agree with the published literature (e.g. Gasse 1986; Patrick and Reimer, 1966). Some of the species, which were found in the plankton of the New River Lagoon and in the literature (*Brachysira neoexilis*, *Synedra ulna* and *Nitzschia gracilis*) are noted to be shallow plankton forms. The other species that were found in the plankton of the New River Lagoon are regarded as epiphytic or littoral species. This implies that these species have detached from these environments and have become part of the marginal lake water environment. The species found in the side streams are also not completely in agreement with the literature. This is not surprising because this environment is transitional being at the edge of the lake system and the beginning of a creek. The species found here are also mainly epiphytic species. Caution needs to be exercised when interpreting the sediment samples as these tend to be a reflection of all the environments that have an input into the system. One key point which the habitat divisions clearly show are the

differences between the nominate forms and their varieties. *Brachysira neoexilis*, *Nitzschia amphibia* and *Navicula radiosa* were all found in different habitats from their varieties. This is evidence that it is important to employ careful taxonomy to ensure that ecological information is not lost. The discovery of these variations will enable a much more informed interpretation of the fossil sequences from this area.

5.5 The role of habitat

In order to investigate the role of habitat further the main data set was separated into the three habitat categories and these were analysed separately.

The distribution of the epiphytic samples in the dominant data set is predominantly explained by the first axis which has an eigenvalue of 0.7327 (this is significantly higher than axis two) (Figure 5.14). The values for the full data set are very similar. The first group of outliers is composed of Almond Hill and Progresso Lagoons (circle). The species that differentiate these sites are *Fragilaria fasciculata*, *Brachysira neoexilis* and *Denticula elegans* (Figure 5.15). These species are not regarded as epiphytic species according to the New River Lagoon data set. Their inclusion suggests that these species can be found in different types of environment and the conditions/ habitats available in Almond Hill and Progresso enable these species to be present in epiphytic habitats. The conductivity values in Almond Hill and Progresso Lagoons are high compared to the other sites that preserved diatoms. These species could have a competitive advantage over others due to an ability to withstand higher conductivity levels and therefore they flourish. The samples were studied under the light microscope after they had been treated in acid (see Chapter 4 for details). This meant that it could not be determined whether the diatoms being studied were actually attached to the sampled vegetation i.e. it is possible that the samples could be contaminated with diatoms from other habitats. The rest of the epiphyte samples form a group (filled circle). This is likely to be a function of the similarity of vegetation types sampled.

Plankton samples were analysed and it is the first axis of the dominant plankton data set that explains most of the variance having an eigenvalue of 0.6919 (Figure 5.16). This is the same as in the full data set. The first axis is also very long which suggests that this is a distinct environmental gradient that the samples are responding to. The New River Lagoon is an open system and therefore it is likely that the system does not support what would be regarded as true planktonic species. The plankton may be composed of species that are faculatively planktonic or indeed the plankton may be dominated by other forms of algae. There are no distinct clusters in this data set. The site which is most different is Aguacaliente (circle). This sample has a very limited flora and is entirely dominated by *Nitzschia palea* which is not as common in any other site (Figure 5.17). Other species present include: *Nitzschia calida* and *Schistauron crucicula*. These are found in medium conductivity waters in epiphytic environments. This sample was from very shallow water in a vegetated zone so this might be expected. Gasse (1986) found *Nitzschia palea*, when in large numbers, an indicator of eutrophic conditions. Aguacaliente Swamp was the home for a number of cattle. These would have contributed to the creation of a eutrophic environment. This was not picked up in the water chemistry results because nutrients were not measured at this site.

The sediment samples are generally stretched out along the first axis which has an eigenvalue of 0.82. The first axis is long which indicates that this represents a strong environmental gradient. The second axis also has a high eigenvalue at 0.68. This is also a long axis and is therefore a significant environmental gradient that the samples are responding to. The sites (Figure 5.18) are stretched out along the first axis with three obvious exceptions: Southern Lagoon, Monkey tail and Almond Hill (triangle). It is not possible to differentiate the species that are causing these sites to separate because there is such a large degree of scatter within the species data (Figure 5.19). Within the rest of the sites it is apparent that the sites that are towards the top end of axis one are more coherent than those at the lower end of axis one. These sites are shown by closed circles and include Hillbank, Kates Lagoon, Lamanai, Cobweb Swamp, Botes Lagoon and Outpost. The species that are associated with these sites include: *Brachysira neoexilis*, *Navicula radiosa*, *Mastogloia elliptica* var. *dansei*,

Denticula elegans and *Nitzschia amphibia* var. *rostrata* (Figure 5.19). These species are all found in the sediments groups in the New River Lagoon. The rest of the sites are shown by open circles. There is quite a degree of scatter within the species data for these sites.

It is apparent from this investigation that habitat does play a key role in differentiating between species assemblages. The sampling system needs to be carefully managed so that each habitat is visited to enable the differences/similarities to be clearly defined. One way in which epiphyte samples could be categorised further would be through the identification of the plant samples to which they are attached. This data set would be improved with a much more detailed survey of the lagoons plankton to determine whether indeed it is comprised of facultative species or is dominated by other forms of algae.

5.6 Summary

The analysis of the modern diatoms of Belize allows the following conclusions to be made:

1. The sites which were sampled contained a range of conductivities from marine to freshwater. Many of the former sites did not preserve diatoms within them.
2. The samples from lakes in northern Belize show a uniformity to the diatom species that are found.
3. The sites that were consistently different were: Southern (sed), Rio Bravo (sed), Aguacaliente (pla), Irish Creek (sed), Almond Hill (epi), Progresso (epi) and Monkey Tail (sed).
4. It is apparent from the 1999 water chemistry data set that the lagoons sampled can be approximately divided into three types: freshwater, calcium-sulphate and sodium-chloride dominated.
5. In order that a much more detailed understanding of the relationship between diatom species and water chemistry can be established for Belize a much more extensive collection of water chemistry data needs to be undertaken.

6. A checklist of species and the habitat in which they are found has been made. The coherence between the Belizian samples and the literature implies that, at least for habitat, there is a degree of uniformity over space.
7. Samples from the New River Lagoon highlight the importance of habitat in differentiating between diatom samples.

5.7 The relationship between the fossil and modern data sets

One of the central reasons behind collecting the modern diatom samples was to enable a greater understanding of the fossil data. In order to achieve this aim a combined data set of the two long cores analysed for diatoms (Lamanai 1999 and Hillbank 1998 (Chapters 6 and 7)) and the modern diatom samples collected from all over Belize was created. In this section the complete data set refers to the data set comprising all the modern and core samples. The New River Lagoon data set is made up of the core data and only the modern samples collected from the New River Lagoon.

5.7.1 The complete data set

The eigenvalues for this data set are 0.4992 and 0.3915 (Figure 5.20). These are fairly low which suggests that these axes do not explain all the variance in the data set and therefore the associations between the sites may not be stable. The three data sets all plot in different zones which suggests that they are not related. The modern (triangles) and Hillbank (filled circle) data form a continuum and the Lamanai (circle) data is much less coherent. This suggests that there has been much more variability in the Lamanai species assemblages through time. Samples from the top of the Hillbank sequence are slightly separated from the rest. It is these depths which are most similar to the Lamanai data. This is due to the dominance of *Denticula elegans* in these levels.

5.7.2 The New River Lagoon data set

The two fossil data sets are both from the New River Lagoon. The modern diatom populations from this lagoon are therefore the most relevant to compare to the core material. Figure 5.21 highlights the distinct differences between the three data sets and the eigenvalues for the axes are low at 0.3169 and 0.2328. One of the Hillbank modern samples is found amongst the Hillbank core data. This sample was from deeper water than the core. The modern sample, which is most different from all the samples analysed, is a plankton sample from Lemonal stream that flows into the New River Lagoon and is far away from any other site sampled. As there is only one overlapping site this limits the inferences which can be made from the modern data set. This highlights the necessity of multiple coring and the collection of a wide range of modern samples so that a large system, such as the New River Lagoon, can be truly understood. Despite extensive sampling this may still not be possible because the modern environment may be very different from that experienced in the past.

5.7.3 The dominant diatom species data set

In order to gain a clearer understanding of the main species which have driven the differences between the sites, a data set was created which contained species that were present at the 5% level or higher in either Lamanai, Hillbank or the modern data set (Figure 5.22). Although this resulted in the three data sets being much less coherent, the modern data set is more closely related to the two cores when just the dominant species are considered. The eigenvalues of the axes are 0.506 and 0.3661 which is about the same as the main data set. Sites which occur in the same zone as the Hillbank samples are from Kates, Progresso, Doubloon, Honey Camp and the New River Lagoon. Samples from Aguacaliente, Progresso, Monkey Tail and Irish Creek separated from the main cluster of modern samples. These have been stretched along the main axis in a similar manner to the Lamanai samples. This is unexpected as these are sites which were identified as outliers in section 5.6 and may be a

function of the limited number of species used in this data set which may have forced associations between sites.

Figure 5.23 allows an understanding to be developed as to which species are driving the differences between the samples.

Modern: *Achnanthes minutissima*, *Brachysira neoexilis* and *Encyonema carina*. The first two species are littoral/epiphytic species that have wide tolerances. The latter is present in high numbers throughout the data set.
Hillbank: *Navicula radiosa* and *Denticula elegans*. These are littoral/bottom mud/marsh species.
Lamanai: *Cyclotella distinguenda*, *Nitzschia amphibia*, *Achnanthes exigua* and *Denticula tenuis*. The first two species are faculatively planktonic/littoral species and *Achnanthes exigua* is a freshwater littoral species. *Denticula tenuis* is only found at depth in Lamanai and is not a common species. It is thought to be found in waters of medium conductivities in littoral environments.

Mastogloia smithii var. *lacustris* is in the centre of the diagram suggesting that it is common to all the samples.

The species in Hillbank and Lamanai are different, but they represent the same type of environments. Lamanai has a much more diverse flora in the fossil data and this is reflected in its more scattered distribution in the Canoco analysis. These results demonstrate that there are tangible differences between Hillbank and Lamanai. What are not clear are the forcing factors which have resulted in these variations. The most likely mechanisms are the amount and type of habitat availability because water chemistry values are very similar in both sites. It also possible that the forcing factor could be a variable that was not measured

5.7.4 The New River Lagoon dominant diatom species

The same analysis was then undertaken on the New River Lagoon data set. This shows the same pattern of sample distribution as the full data set. The eigenvalues for the axes are 0.5131 and 0.332 (Figure 5.24). The slightly higher eigenvalues for this reduced New River Lagoon data set as compared to the full data set suggests that it is the rarer species outside the New River Lagoon in the modern environment that are decreasing the associations between sites. The modern samples themselves show a degree of spread, which is probably related to the different habitats from which the material was collected. The close relationship between the Hillbank and modern samples could be related to the bias in modern samples towards those from the Hillbank area. The outlying samples from the modern cluster are the ones from Lamanai. The same pattern of species occurs in the New River Lagoon data set to the full data set (Figure 5.25). This means that these species are the key species for explaining distribution in both modern day and historical Belize.

5.7.5 Implications

The modern assemblages in the New River Lagoon do not appear to be related to the fossil samples studied. Analysis in Chapters 6 and 7 reveals that the top sediments in the two Livingstone cores, do not represent modern day conditions due to the unconsolidated sediment found in the lagoon. Kullenberg cores were also taken from Lamanai and Hillbank. These capture the sediment/water interface and therefore are more likely to represent modern day conditions onwards. These, however, do not have diatoms preserved within them which may suggest that the Kullenberg cores have not successfully collected the most recent sediments because the modern samples were found to contain diatoms. This suggests that the following changes have occurred through time:

1. Diatoms are preserved in the modern day environment although not in the plankton samples taken.
2. Conditions are currently not suitable for diatoms to be preserved in any more than the most recent sediments. This could be due to the mixing of the top

sediments which would encourage processes such as dissolution and fragmentation.

3. The system shifted back to 'preserving conditions' at some point in the past. The system has changed though because if conditions were the same, then these core samples would have plotted amongst the modern samples.
4. Through time the systems have moved between preservation and dissolution being the dominant processes.

Conclusions can also be drawn concerning the relationship between Hillbank and Lamanai:

1. The degree of sample cluster in Hillbank is much greater than in Lamanai. This implies that the species assemblages have changed much less through time in Hillbank than in Lamanai. One reason for this might be that the cores are located on opposite sides of the lagoon with Lamanai being located by forest and Hillbank by marsh. Through time it is likely that the forest system has undergone changes that are both natural and human induced. Marsh environments are much harder to manipulate and therefore likely to have a more stable diatom population.
2. Although many of the main species are common to both cores, the mix of assemblages and the dominance of these main species differ enough to separate the sequences. This could also be a function of Hillbank's more stable past than Lamanai.
3. This study highlights the need for multiple cores in a basin as it cannot be assumed, especially in a lagoon as large as the New River, that one core will provide an accurate reflection of the changes which it has undergone through time.

5.8 Summary

Through the analysis of the main data set it is apparent that there are sites which are outliers. Almond Hill, Progresso, Monkey Tail and Aguacaliente are four of those sites. There is no apparent relationship in the main data set between habitat and site

groupings. Through the analysis of the New River Lagoon it was possible to assign habitats to the species due to the clear divisions of the sites sampled. This was possible because samples were collected from different habitats in the same area allowing differences in diatom species to be more keenly recognised. The collection of water chemistry data has enabled some initial categorisations of the site which is helpful in terms of understanding the general limnology of north Belize.

5.9 *Mastogloia smithii* var. *lacustris*: A study in Belize

The issues raised in Chapter 4 and in the previous analysis of the modern data set prompted a study of *Mastogloia smithii* var. *lacustris* which is one of the diatoms species common to the samples studied both in the modern and fossil environment. This investigation had three aims:

1. To determine the consistency of diatom characteristics within a variety of habitats and geographical locations.
2. To determine whether these characteristics match those cited in the literature (Hustedt, 1959; Patrick and Reimer, 1966; Krammer and Lange-Bertalot, 1986) and in Van Heurck's type material (N 47, BM 26358).
3. To develop a greater understanding of diatom taxonomy in northern Belize.

Mastogloia smithii var. *lacustris* is a dominant form in the New River Lagoon reaching up to 36% of the individuals from a sampled population. This lagoon has been investigated in terms of its modern diatom flora (this chapter) and its palaeoenvironmental history (Chapters 6 and 7). These two studies are linked because through the unravelling of the species modern characteristics a greater understanding of the fossil record will be developed. *Mastogloia smithii* var. *lacustris* according to the literature is found in brackish waters in coastal areas and frequently in the littoral zone of freshwater systems (Krammer and Lange-Bertalot, 1986). Patrick and Reimer (1966) found it most commonly in freshwater lakes as a shore form; sometimes in springs and occasionally in slightly brackish waters. The key difference between the ecology of *Mastogloia smithii* var. *lacustris* and

Mastogloia smithii appears to be that the variety is found only in the littoral and in waters of lower conductivity than the nominate form (Hustedt 1959).

5.9.1 Methods

Width/Striae measurements were taken on 40 diatoms from each site and on type slides from *Mastogloia smithii* var. *lacustris* (Van Heurck N 47 26358) and *Mastogloia smithii* (Coll WM Smith BM 24346). The width/striae ratio does not vary through a diatom's life cycle (D. Mann pers.com 2001) and therefore it is a good measure of difference between populations. Mann-Whitney tests were performed in order to determine whether there were significant differences between the groups measured.

5.9.2 Results

Thirteen samples of *Mastogloia smithii* var. *lacustris* were studied. Each sample was tested against the remaining twelve. Groups of sites were created that were deemed by the Mann-Whitney test to be not significantly different from one another at the 95% level. The three tables created highlight:

1. The characteristics of the original type material of the species *Mastogloia smithii* and *Mastogloia smithii* var. *lacustris* (table 5.1).
2. The characteristics published in the literature (table 5.2).
3. The differences in width/striae characteristics exhibited in the modern habitats of New River Lagoon, Belize (table 5.3).

Table 5.4- Type Material (illustrated in Figure 5.26)

Authority	Mean Width (μ)	Mean Striae (in 10μ)	Mean Ratio
M smithii var. *lacustris* (VH)	10	20	0.5
M smithii (Smith)	13	21	0.61

Table 5.5 – Published Descriptions

Authority	Width (μ)	Striae (in 10μ)	Ratio Range
Hustedt (1959)	8-14	15-18	0.53-0.78
Patrick and Reimer (1966)	8-11	15-16	0.53-0.69
Krammer and Lange-Bertalot (1986)	8-14	15-18	0.53-0.78

Table 5.6 – Belizian Modern Samples (illustrated in Figure 5.27)

Site	Mean Ratio	Mann-Whitney
Outpost Reeds	0.43	Group 1
Outpost Flat Grass	0.43	Group 1
Outpost Sediment	0.52	Group 2
Outpost Aquatic Algae	0.52	Group 2
HB 3 Reeds	0.45	Group 3
HB 3 Aquatic Algae	0.48	Group 3
HB 3 Sediment	0.5	Group 4
HB 1 Algae	0.43	Group 5
HB1 Reeds	0.45	Group 5
HB1 Sediment	0.45	Group 5
HB 2 Sediment	0.44	Group 5
HB 2 Reeds Sediment	0.45	Group 5
HB 2 Cutting Grass	0.45	Group 5

These sites are shown on Figures 5.2 and 5.3.

5.9.3 Discussion

From studying these tables the following points can be immediately made:

1. The sediment and reed populations of *Mastogloia smithii* var. *lacustris* in the sites Outpost and HB 3 can be differentiated from one another. These are illustrated in appendix 5.
2. This relationship does not hold for sites HB 1 and HB 2.

3. The width/striae ratios of the New River Lagoon populations do not fall within the ranges published in the literature for this species.
4. The HB 3 sediment site is the only one which matches the Van Heurck type material.

The New River Lagoon is a large freshwater system which eventually connects to the sea via the New River. The west shore is dominated by forest vegetation (Outpost and HB 3) and the east shore is dominated by marshland (HB 1 and 2). This is shown clearly in Figure 3.3.

The key differences between the sites HB 1/2 and Outpost/HB 3 are the water depth and the role of the marshland. HB 1/ 2 are shallow water sites and therefore the chance of mixing between different habitats is increased. The marshland adjacent to the southwest shore (where HB 1/ 2 are located) is an integral part of the lake system due to the seasonal flooding of this area during the wet season. With no barriers to inhibit movement between the lake and the marsh the dominant input of diatoms are likely to be epiphytic species from the marsh environment. Thus, the *Mastogloia smithii* var. *lacustris* that enter from the marsh would be from a 'reed' population. Both the sediment and reed habitats sampled in HB 1 and 2 are in the range of the ratios exhibited by Outpost and HB 3 reed populations.

The distinction in Outpost and HB 3 is clearly between a reed type and a sediment type. If one takes the mean measurements of the reed populations and the mean measurements of the sediment populations from these two sites, the following mean ratios are produced:

1. Reed: 0.44 (8.5/20)
2. Sediment: 0.53 (10/19)

These ratios are clearly different suggesting that the two populations which have been delimited in this investigation, are distinct from one another.

A sediment core was collected in 1999 from Lamanai (Figure 1.1). The *Mastogloia smithii* var. *lacustris,* that were found in this sequence, fall into two width/striae ratio categories which equate to the reed and sediment populations found in the modern environment. This suggests that two populations of *Mastogloia smithii* var. *lacustris* have been present in the New River Lagoon for at least the last 3440 ^{14}C years BP. A sediment core has also been taken from the east shore (Hillbank 1998) and the distinction between the two types of *Mastogloia smithii* var. *lacustris,* as one would expect, is not present. The ability to differentiate between two types of *Mastogloia smithii* var. *lacustris* provides additional insight in to the environmental changes that have occurred at the Lamanai site because it enables inferences to be made concerning the predominance of reeds in the vicinity of the site.

The second aim of the investigation was to relate the characteristics of the populations found in the New River Lagoon to those cited in the literature (Hustedt (1959); Patrick and Reimer (1966); Krammer and Lange-Bertalot (1986)). The characteristics of the modern diatoms from Belize and the literature do not overlap. The reed population is distinctly different, but the sediment population is closer to the smaller end of the range cited. This raises two points. Firstly that the sediment population in the New River Lagoon is likely to be the 'true' *Mastogloia smithii* var. *lacustris* and the reed population is the evolved population. This line of argument could be followed up with the rationale that the reed population is specific to either the New River Lagoon or Belize. This cannot be substantiated because the material from which the literature characteristics were derived is unknown and it could be the case that it was just sediment populations that were studied. If the sites were visited again and sampled for reeds, the same distinction as found in Belize could well be present. Thus, further investigation of the original sites and other geographical locations is needed to determine how widespread the reed type is.

The third comparison was with the type material. The modern sediment populations from Belize are of the same order of magnitude as the type material. No other information is available on the environment from which these type samples were taken and therefore no further inferences can be made. The ratio of the *Mastogloia*

smithii type material falls within the range for *Mastogloia smithii* var. *lacustris* characteristics cited in the literature. This suggests that a careful study of the reasons behind the division of *Mastogloia smithii* var. *lacustris* and *Mastogloia smithii* should be carried out.

The question, which has not been answered by this investigation, is why such a difference would evolve? The type of variation between the 'reed' and 'sediment' population is of the same order of magnitude as for example two demes of *Sellaphora pupula* (David Mann pers com. 2001). This suggests that the explanation behind the two different populations of *Mastogloia smithii* var. *lacustris* may be due to a reproductive barrier; a genetic difference or indeed they may even be different taxa. If there are no barriers to sexual reproduction then the discontinuity between two forms may represent different episodes of sexual reproduction. Laboratory controlled experiments of modern populations would be needed to establish the reasons behind the different morphologies. There is evidence that many species vary in the same way as *Sellaphora pupula* (Mann, 1989) with species being divided into two or more morphologically distinct forms which may or may not be found in the same geographical area. An example of this is the work by Knudson (1953) who found three morphotypes of *Tabellaria flocculosa* coexisting, two in the plankton and one in the epiphyte. Mann and Droop (1996) state that the significance of minor variations in shape and form in unicellular algae is unknown. This study highlights that one reason for such difference may indeed be habitat preference.

To conclude, this study has explored variation on the following scales:

1. Variation between samples.
2. Variation between habitats.
3. Geographical variation within one lake basin.
4. Long term variation.

Inferences have been made concerning one species and its division into two distinct populations. Width/striae measurements were taken to represent the gross

morphology of the specimens. This ratio does not vary through the life cycle and thus the differences between the two populations can be deemed to be stable. The two populations are related to habitat with one being found in reed environments and the other in the sediment. This relationship does not hold for the entire lagoon highlighting the need for surveys of lake systems to be extensive. The characteristics of both populations do not match the literature or type material. It is the reed population which is most distinctive and it is not known whether this type of environment was sampled when creating the characteristics cited in the literature. It cannot therefore be concluded that this reed population is unique to Belize. What it does highlight is that the morphology of species may not be stable within different habitats or geographical areas.

The concept of restricted geographical distribution of diatom species can occur on a number of different scales from being only present in one lake system up to presence in one continent. This can only be resolved if large-scale studies using a narrow species concept are undertaken. This study alludes to the fact that diatom species are not stable in their characteristics and thus to gain a true understanding of a species studies need to be both intensive and extensive. Diatom sample collection needs to be coupled with the collection of water chemistry and habitat information. This work would have a great deal of benefit to palaeoenvironmental studies, as it would ensure that accurate ecological reconstructions are being made. This study also highlights the need for a more specific species concept than exhibited in the Krammer and Lange-Bertalot series (1986, 1988, 1991a, 1991b). The existence of more than one morphological type is important to stress if one is concerned about the diversity of flora at a site. Such diversity will be underrepresented if the types are not considered.

5.10 Conclusions

This chapter provides the first analysis of modern diatom populations in Belize. Through the work which has been undertaken knowledge has been gained concerning species assemblages, the controlling factors behind these, the

relationships between different lagoon systems, the connection between the modern and fossil environment and the specific factors which influence one diatom species in particular. The conclusions which have been reached are subject to modification due to the need to sample a wider variety of sites, habitats and a more through collection of water chemistry variables.

5.11 The Modern Isotope Results

The following table compares the results gained from Belize with values that have been published in the literature for sites in the surrounding area.

Table 5.7

Lake	Authority	Water Type	$\delta^{18}0$
Belize			
Honey Camp Lagoon		Lakewater	2.91 δD 15+/- 0.5
New River Lagoon (Hillbank)		Lakewater	-0.97 δD –5.2 +/- 1.5
Yucatan Peninsula			
Lake Chichcanab	Covich and Stuiver 1974	Lakewater Spring	4 -4.7
Punta Laguna	Curtis *et al.*, 1996	Groundwater Lakewater	-3.92 0.93
Coba	Whitmore *et al.*, 1996	Lakewater	1.18
San Jose Chulchaca	Whitmore *et al.*, 1996	Lakewater	0.5
Sayaucil	Whitmore *et al.*, 1996	Lakewater	5.3
Lake Chichcanab	Hodell *et al.*, 1995	Lakewater	3.24
Guatemala			
Lake Peten-Itza	Curtis *et al.*, 1998	Lakewater	2.62
Lake Yaxha	Curtis *et al.*, 1998	Lakewater	2.33
Petenxil	Curtis *et al.*, 1998	Lakewater	2.71
Quexil	Curtis *et al.*, 1998	Lakewater	3.45
Paxcaman	Curtis *et al.*, 1998	Lakewater	3.21
Salpeten	Curtis *et al.*, 1998	Lakewater	3.52
Sacnab	Curtis *et al.*, 1998	Lakewater	3.85
Macanche	Curtis *et al.*, 1998	Lakewater	3.08
Regional	Rozanski *et al.*, 1993	Rainwater	-4.0
Yucatan Peninsula			
Punta Laguna	Curtis *et al.*, 1996	Rainwater	-3.91
Lake Chichcanab	Covich and Stuiver, 1974	Rainwater	-6.1
Guatemala			
Peten-Itza	Curtis *et al.*, 1998	Rainwater	-0.98

When liquid water and water vapour are in equilibrium, the vapour is isotopically lighter with respect to both D/H and $^{18}0/^{16}0$ than the liquid. The isotopic composition of seawater, by definition of the SMOW scale is 0‰ for both $\delta^{18}0$ and δD. The δD and $\delta^{18}0$ values in precipitation and hence freshwaters generally plot close to a straight line $\delta D = \delta^{18}0+10$. The position along this line (the meteoric water line) of a particular rainfall depends primarily on the amount of precipitation that has occurred between the time the air mass left the ocean and the time of the particular rainfall.

With respect to the published data it is apparent that Honey Camp Lagoon is very similar to Lake Peten-Itza and Lake Petenxil, whereas the New River Lagoon equates to rainwater measured at Lake Peten-Itza. This is extremely interesting because it highlights two key points. Firstly that the systems in Belize are more similar to those in Guatemala than those in the Mexican Yucatan Peninsula. This is most likely to be due to the similarity in the climate of Belize and Guatemala. Secondly the results from the New River Lagoon suggest that rainwater enters this system and the levels of evaporation are not strong enough to enhance its isotopic signature. This is likely to be as a result of its open nature.

Figure 5.28 contains data from Mexico and Cuba (Metcalfe, unpublished data). The two results from Belize fall exactly on the Cuban trendline. This suggests that these systems have very similar controlling mechanisms. This is not surprising due to both areas being under the influence of the Caribbean Sea and underlain by carbonate geology. The comparison of modern isotope data enables a much greater idea of regional dynamics to be developed.

This chapter has dealt with the modern results from Belize. The next three chapters will discuss the results from the sediment cores collected.

Hillbank, New River Lagoon

Basemap: DOS Sheet 15, Edition 5-GSGS (1993), Scale 1:50,000
Projection: Universal Transverse Mercator (Zone 16)

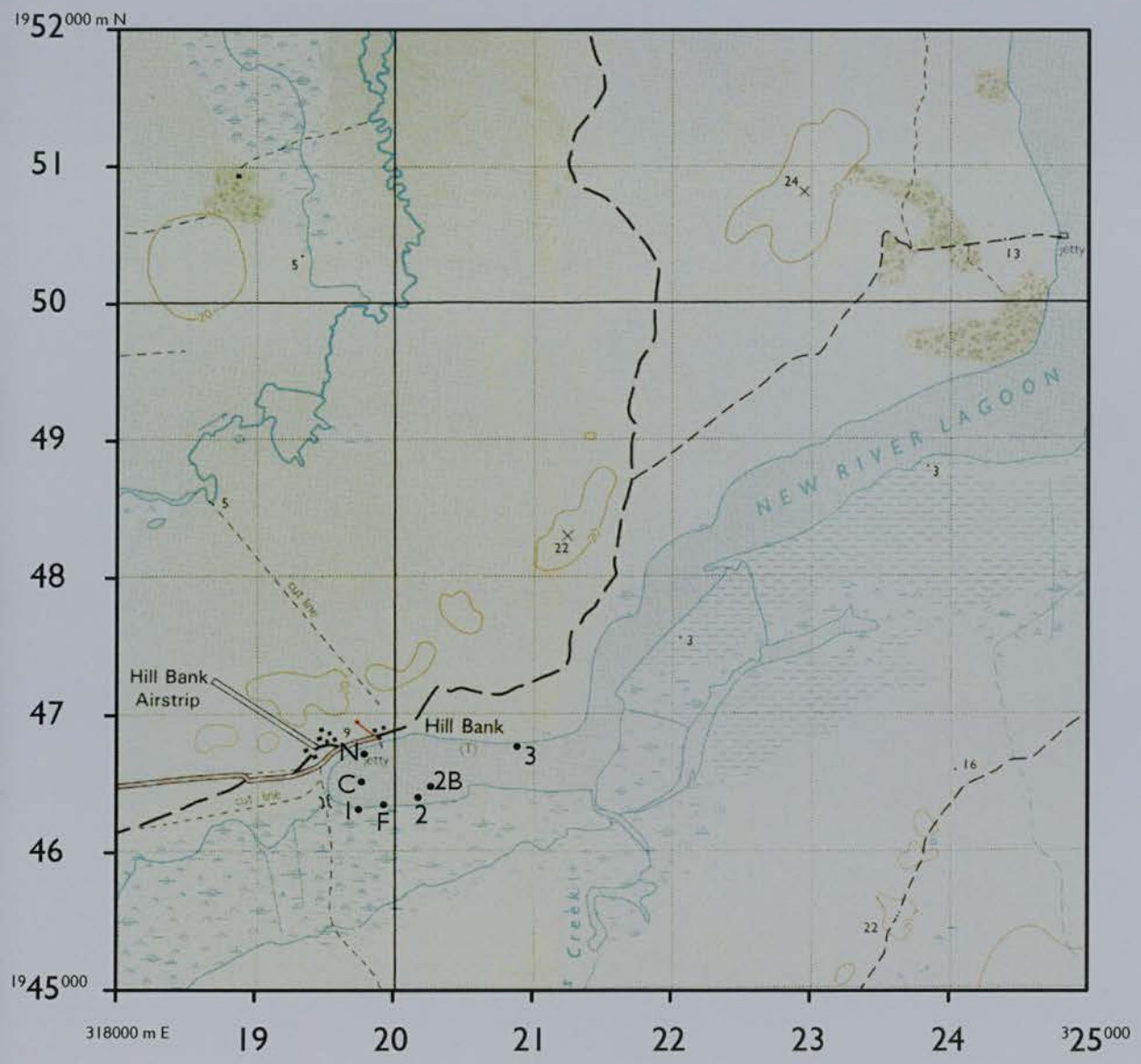


Figure 5.2
Modern

Modified from Murray (unpub.)

1 - Hillbank 1 2000
2 - Hillbank 2 2000
2B - Hillbank 2B 2000
3 - Hillbank 3 2000
C - Centre Hillbank 1998
F - Far side Hillbank 1998
N - Near side Hillbank 1998

Lamanai, New River Lagoon

Basemap: DOS Sheets 15, Edition 5-GSGS (1993) & 10, Edition 5-GSGS (1994), Scale 1:50,000
Projection: Universal Transverse Mercator (Zone 16)

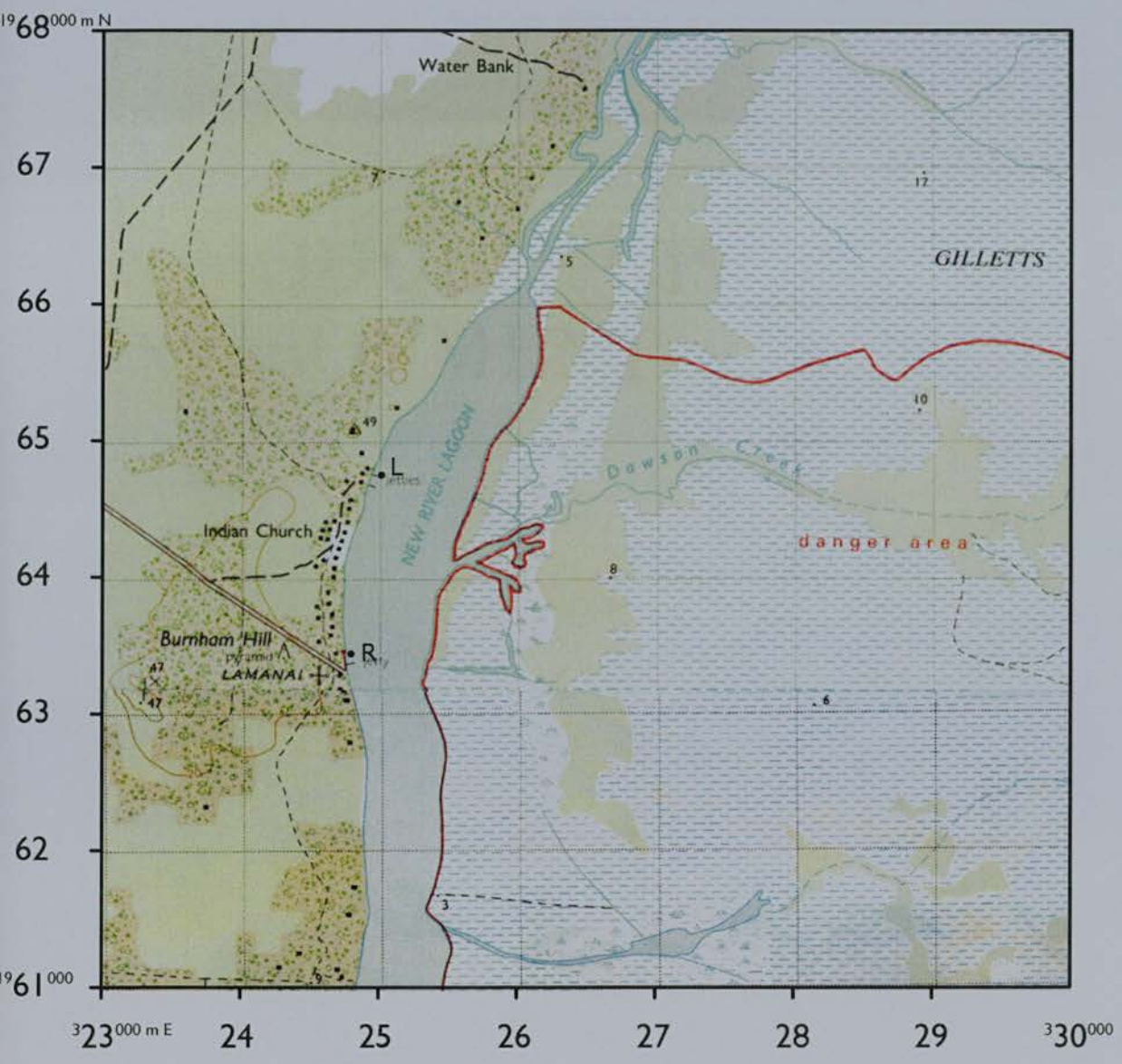


Figure 5.3
Modern Sampling sites 2000:

R and L

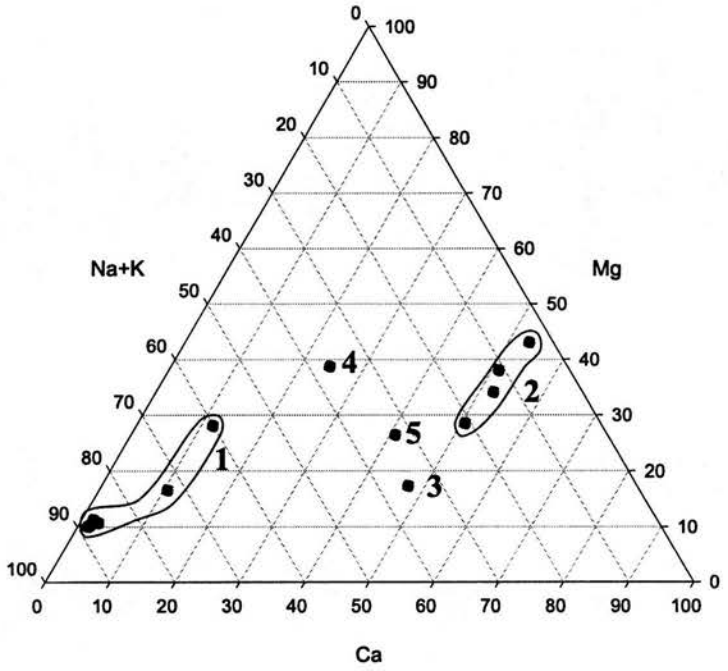
Modified from Murray (unpub.)

Figure 5.4

Sites	Year	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulphate	Bicarbonate	pH	Conductivity mScm -1	Phosphate	Nitrate	Silica
Bluewater Creek	2000	/	6.42	/	/	/	4.16	6.45	7.56	2.19	0.2	0.04	25.8
Booth River	1999	2.43	1.81	0.51	0.01	0.12	6.68	2.75	6.82	0.92	/	/	/
Botes Lagoon	2000	/	0.86	/	/	/	5	1.60	6.61	0.64	0.16	0.024	8
Chiwa Lagoon	1999	0.88	1.39	1.26	0.06	0.39	0.35	1.77	7.21	0.43	/	/	/
Cobweb Swamp	2000	/	1.28	/	/	/	3	2.50	7.26	0.77	0.24	0.12	8
Crooked Tree Lagoon	1999	0.68	0.44	0.52	0.02	0.13	1.21	1.19	8.06	0.6	/	/	/
Doubloon Lagoon	2000	/	3.95	/	/	/	4.16	1.80	8.52	1.48	0.03	0	3.2
Caledonia, New River Lagoon	2000	/	6.42	/	/	/	4.16	3.46	7.65	3.54	0.14	0.02	14.8
Irish Creek	1998	/	/	/	/	0	/	6.39	8.76	0.86	0	0.0019356	4
Lemonal Creek, New River Lagoon	1998	/	/	/	/	0	/	2.16	/	1.07	0	0.00009678	4
Ramgoat Creek, New River Lagoon	1998	/	/	/	/	0	/	5.20	8.44	1.93	0	0.00004839	4
Harry Jones Creek	1998	/	/	/	/	0	/	3.36	8.22	1.37	0	0	4
Harry Jones Creek (side)	1998	/	/	/	/	0	/	1.24	8.7	1.31	0	0.00004839	4
Hillbank 1, New River Lagoon	2000	/	2.80	/	/	/	4.16	3.10	7.88	1.19	0.18	0.003	14.2
Hillbank 2, New River Lagoon	2000	/	2.14	/	/	/	3.37	3.94	8.12	1.29	0.1	0.009	14.4
Hillbank centre, New River Lagoon	1998	/	/	/	/	0	/	2.96	/	1.12	0.006318	0	4
Hillbank far side, New River Lagoon	1998	/	/	/	/	1.81	/	2.96	8.44	1.15	0.0069498	0.00014517	4
Hillbank near side, New River Lagoon	1998	/	/	/	/	0	/	2.96	/	1.12	0	0	4
Lamanai raft, New River Lagoon	2000	/	2.30	/	/	/	4.16	2.90	8.06	0.91	0.24	0.021	12.6
Lamanai, New River Lagoon	1999	1.79	1.17	0.4	0.07	0.23	4.83	1.31	7.29	1.07	/	/	/
Honey Camp Lagoon	1999	1.29	3.07	6.38	0.19	6.21	7.02	2.05	8.3	1.5	/	/	/
Honey Camp Lagoon	2000	/	5.92	/	/	/	4.16	3.40	8.08	1.6	0.36	0.15	27.8
Honey Camp Spring	2000	/	5.26	/	/	/	4.16	2.60	8.19	1.59	0.24	0.047	24
Kates Lagoon	1999	0.82	0.3	0.58	0.03	0.14	0.15	0.98	8.29	0.23	/	/	/
Kates Lagoon	2000	/	1.03	/	/	/	5	1.90	7.76	0.27	0.22	0.094	13.44
Laguna Seca	2000	/	1.19	/	/	/	3	1.90	7.77	0.32	0.1	0.003	16
Laguna Verde	2000	/	2.14	/	/	/	3	2.90	8.65	0.45	0.16	0.17	16
Small Croc Lagoon	1999	1.74	0.98	0.68	0.04	0.29	3.16	1.77	7.04	0.6	/	/	/
Almond Hill Lagoon	2000	/	5.92	/	/	/	185	0	7.4	3.82	0.12	0.018	0
Jones Lagoon	1999	3.85	23.91	180.69	4.08	212.42	29.23	1.48	7.92	23.34	/	/	/
Northern Lagoon	1999	1.21	4.48	35.38	0.82	45.14	5.87	1.56	8.26	5.34	/	/	/
Progresso Lagoon	1999	2.18	3.41	14.65	0.36	17.11	9.29	2.21	8.1	7.25	/	/	/
Southern Lagoon	1999	3.54	22.37	193.18	4.44	162.49	23.69	2.67	8.35	23.3	/	/	/
Wagner Lagoon	1999	1.43	6.39	50.14	1.14	63	8.24	1.77	8.1	7.25	/	/	/
Fabers Lagoon	1999	3.16	17.56	146.49	3.32	46.08	17.97	1.84	7.95	16.99	/	/	/
Monkey Tail River	1998	/	/	/	/	0	/	0.84	7.55	2	0	0	4
Aguacaliente Swamp	1999	4.32	3.49	0.27	0.03	0.06	19.57	0.92	8.1	1.63	/	/	/

/ signifies no data
All Data Is In MEQ

Figure 5.5 Water Chemistry Data (1999)



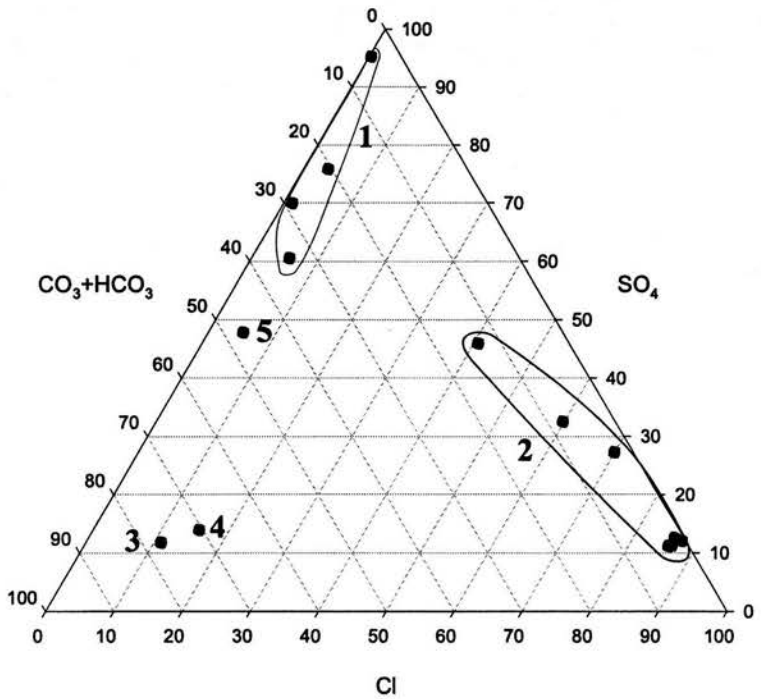


Figure 5.6

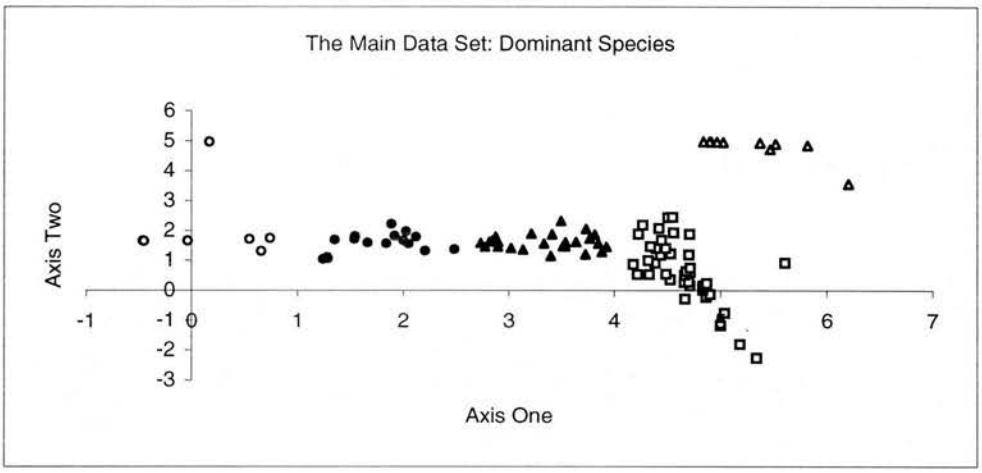
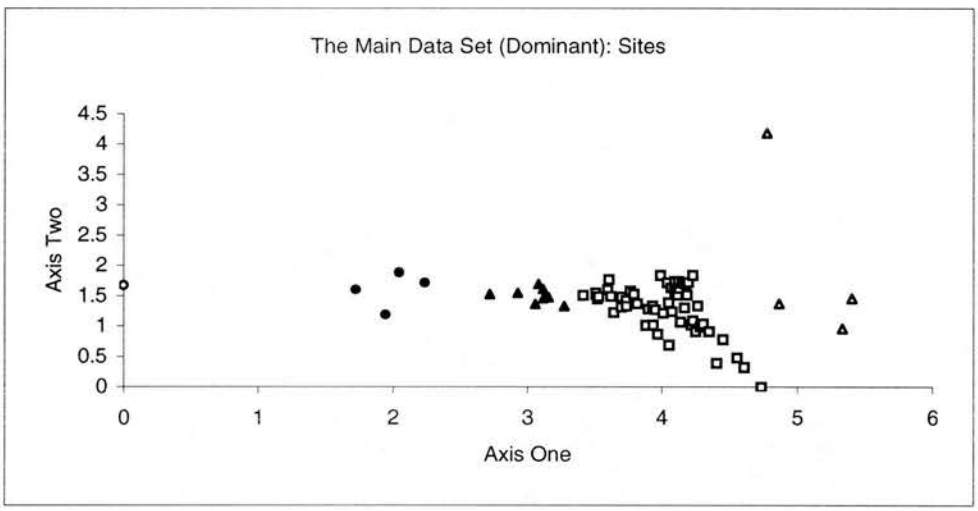


Figure 5.7



Key:

Group 1: Southern Lagoon (sed) *Navicula florinae, Cocconeis placentula* var. *eugylpta* and *Diploneis parma* (circle)

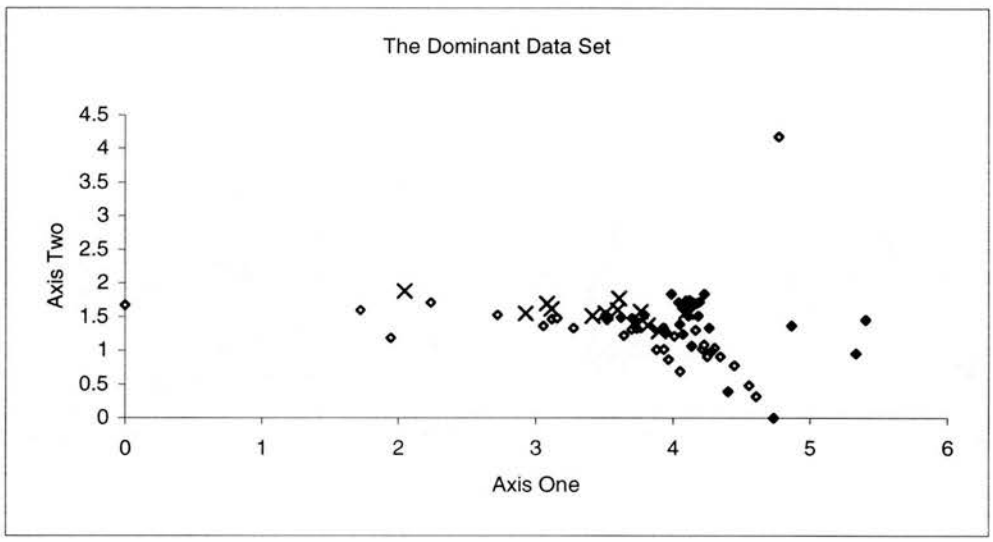
Group 2. Rio Bravo (sed), Monkey Tail River (stones), Aguacaliente Swamp (pla) and Irish Creek (sed) Navicula radiosa var. tenella. *Cymbella microcephala*, *Nitzschia palea*, *Gyrosigma acuminatum*, *Navicula cuspidata* and *Schistauron crucicula*. (filled circle).

Group 3. Progresso Lagoon (sed) and Almond Hill. *Achnanthes minutissima* (triangle).

Group 4. Rio Bravo (pla), Monkey Tail River (sed), Irish Creek (pla), Lemonal Creek (pla), Chiwa Lagoon (sed) and Harry Jones Creek (sed). *Brachysira neoexilis, Brachysira neoexilis* var. *small, Brachysira neoexilis* var. *capitate*, *Encyonema carina*, *Nitzschia amphibia* and *Nitzschia gracilis*. (filled triangle).

Group 5. This contains most of the sites sampled including Crooked Tree Lagoon, Booth River, Kates Lagoon, Lamanai and Honey Camp Lagoon. *Denticula elegans, Mastogloia smithii* var. *lacustris*, *Gomphonema gracile*, *Brachysira neoexilis* var. *large* (square).

Figure 5.8



Key: Sediment (diamonds), Epiphyte (filled diamonds), Plankton (crosses)

This graph shows the distribution of samples collected in Belize highlighting the differences between diatom habitats.

Figure 5.9

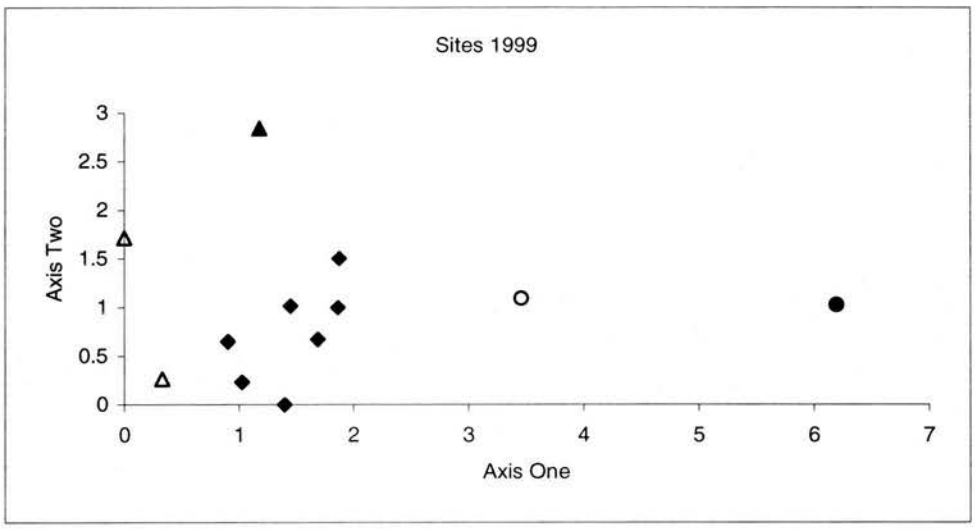
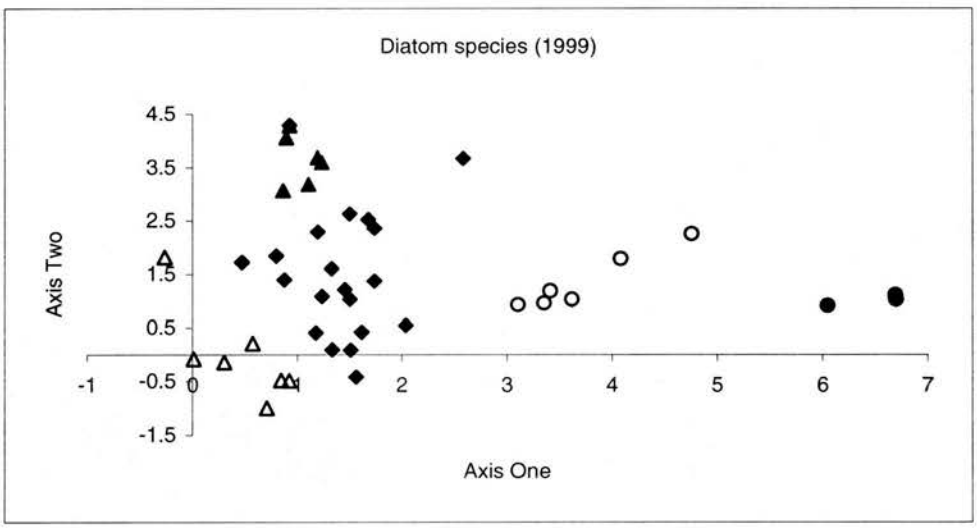


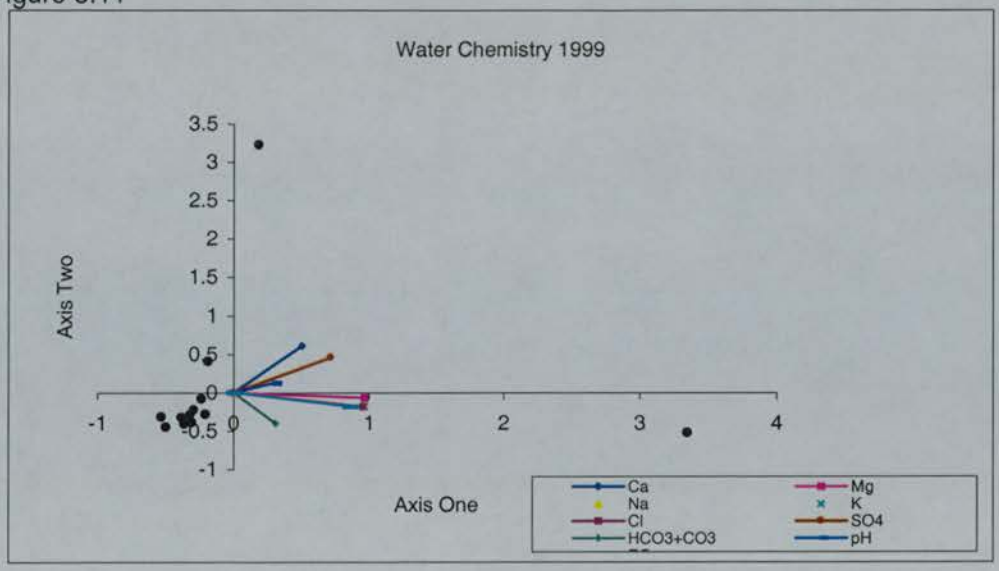
Figure 5.10

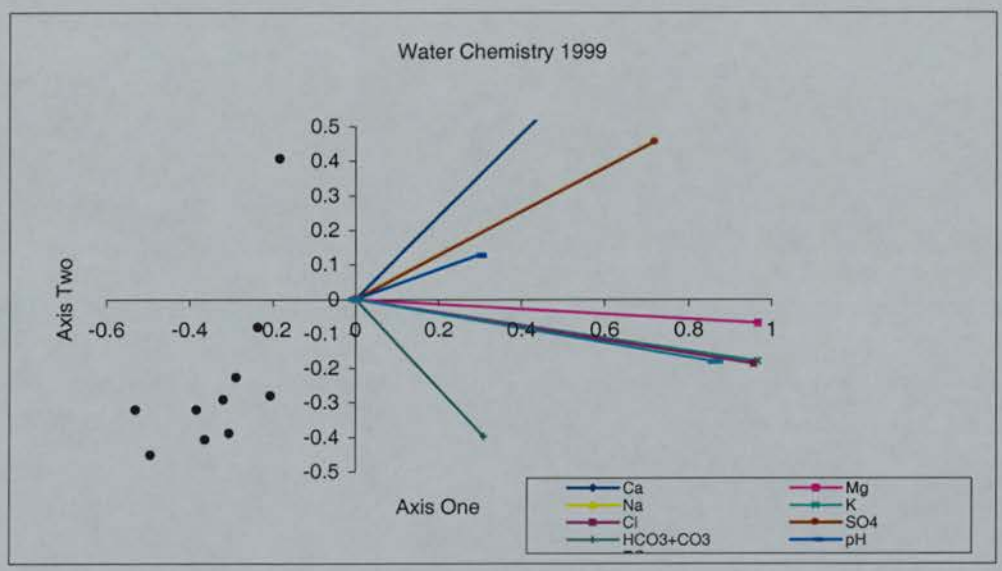


Key: Water chemistry 1999 data set.

1. Southern Lagoon (filled circle): *Achnanthes exigua*, *Cocconeis placentula* var. *euglypta*, *Navicula florinae* and *Fragilaria brevistriata*.
2. Aguacaliente Swamp (circle): *Schistauron crucicula*, *Nitzschia palea* and *Achnanthes minutissima*.
3. Progresso Lagoon (triangle): *Fragilaria fasciculata*, *Denticula elegans* and *Nitzschia amphibia*.
4. Chiwa Lagoon (filled triangle): *Brachysira neoexilis* var *small, Aulacoseira granulata* and *Diploneis ovalis*.

Figure 5.11





1999 Water Chemistry data.
The separation of the water chemistry variables match the two groups of lake-type highlighted in Figure 5.5.
The second graph has had the outlying sites removed so that the distribution of the arrows can be seen more clearly.

Figure 5.12

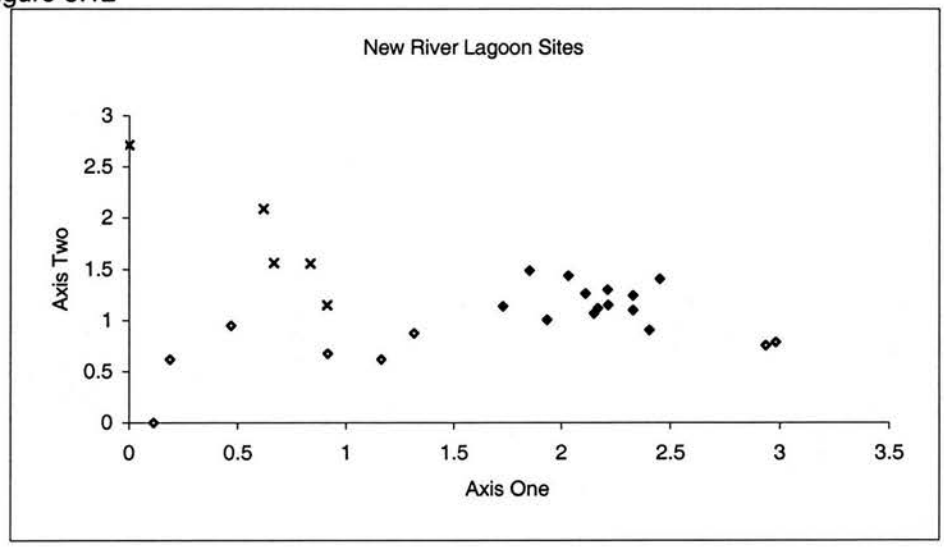
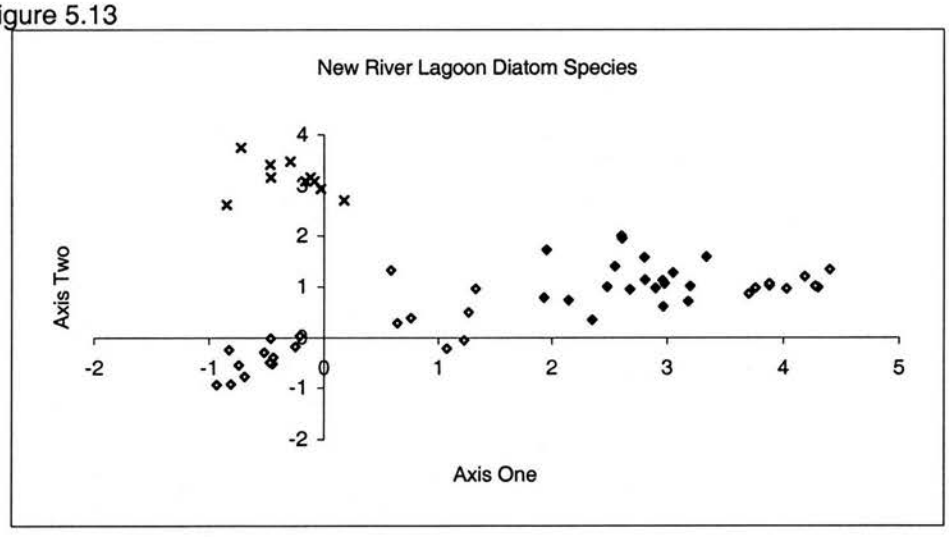


Figure 5.13



Key: Epiphyte (filled diamond), sediment (diamond), plankton (crosses). This figure highlights the clear differences between habitat in the New River Lagoon. The species are noted in section 5.4.

Figure 5.14

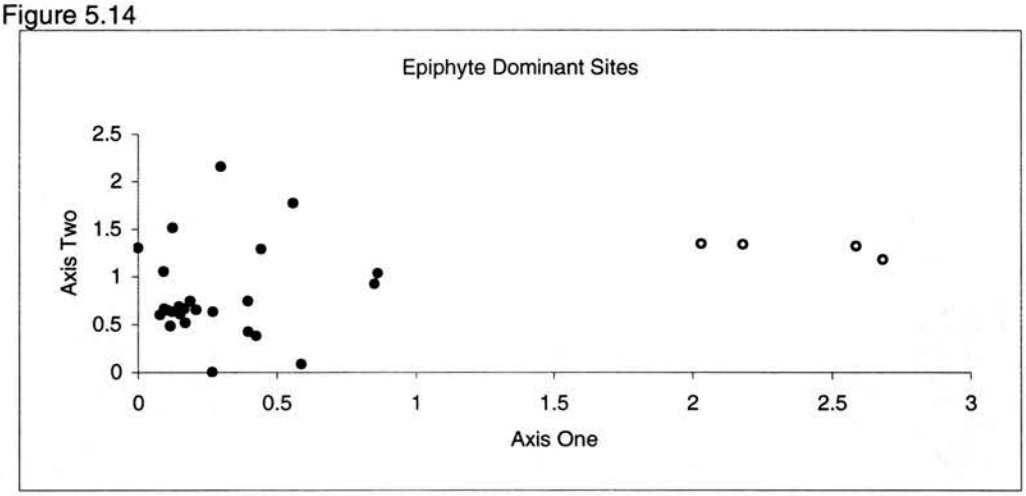
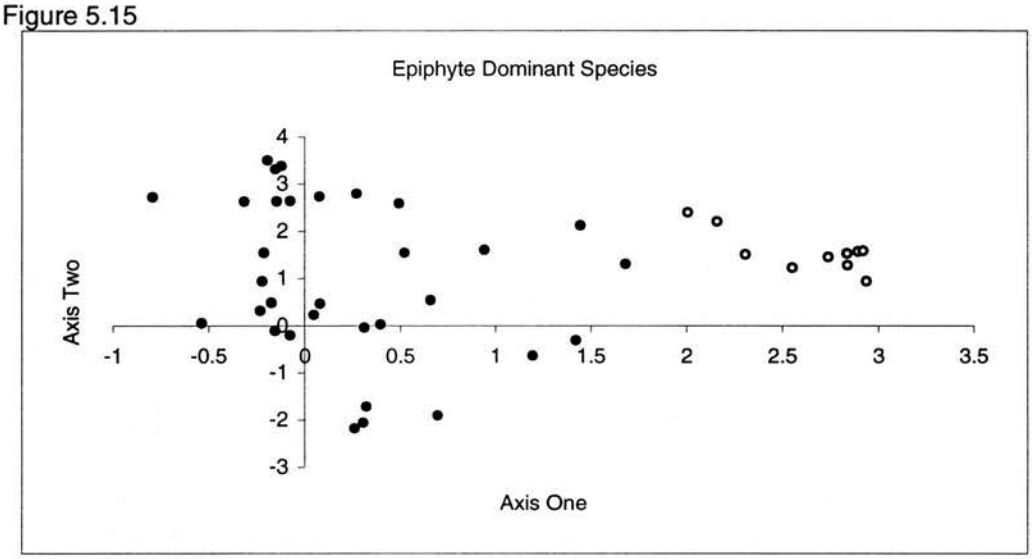


Figure 5.15



Key: Almond Hill and Progresso Lagoons (open circle). The species that differentiate these sites are *Fragilaria fasciculata*, *Brachysira neoexilis* and *Denticula elegans*. These two sites had much higher conductivity values than the other sites that preserved diatoms.

Figure 5.16

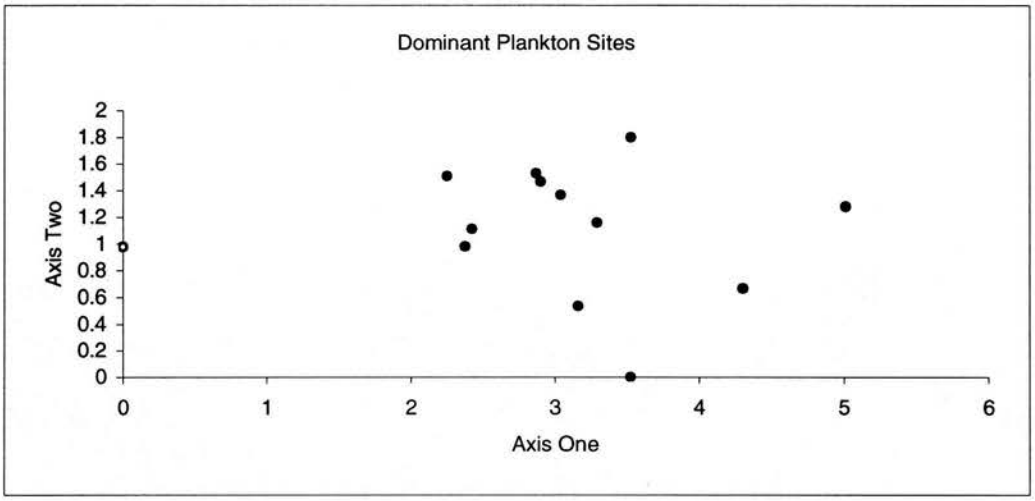
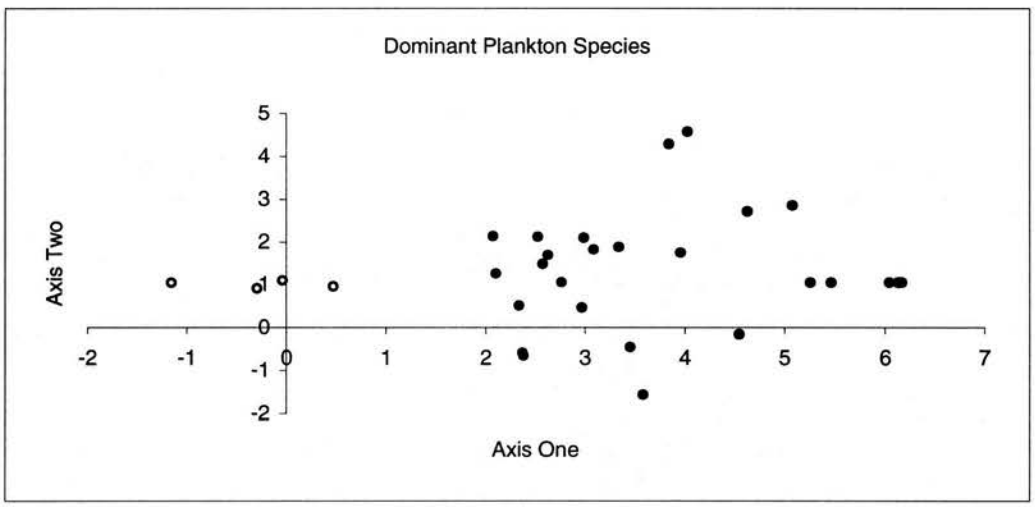


Figure 5.17



Key: Aguacaliente Swamp (open circle) This site is dominated by *Nitzschia palea*. The lack of clustering in this data set could be due to the fact that the samples were not composed of a true plankton flora.

Figure 5.18

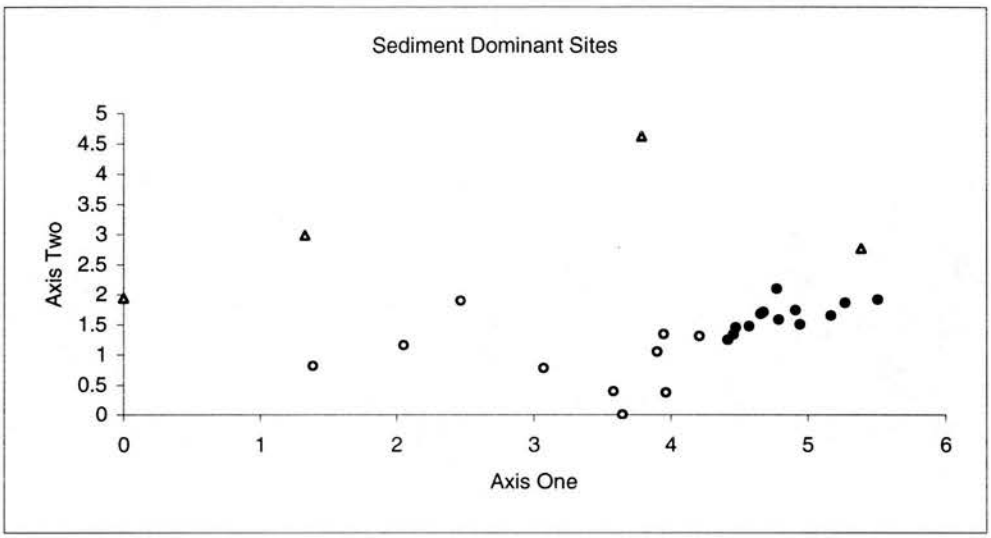
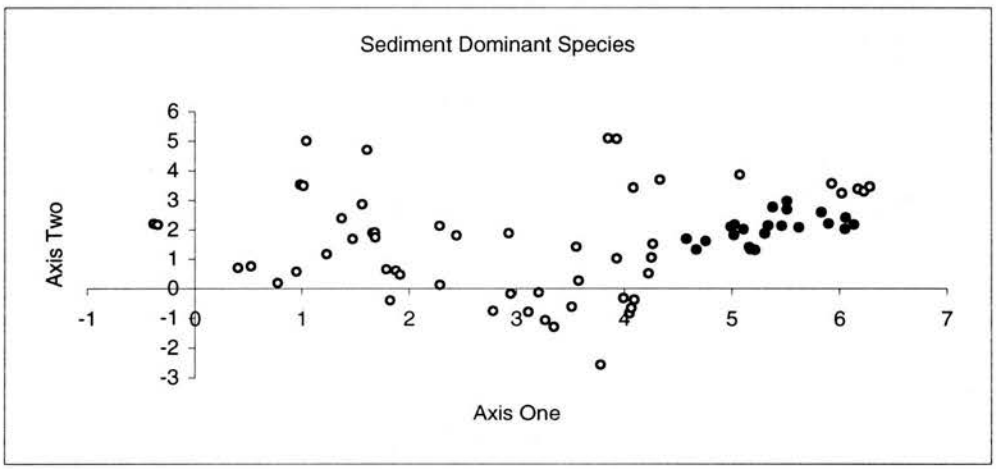
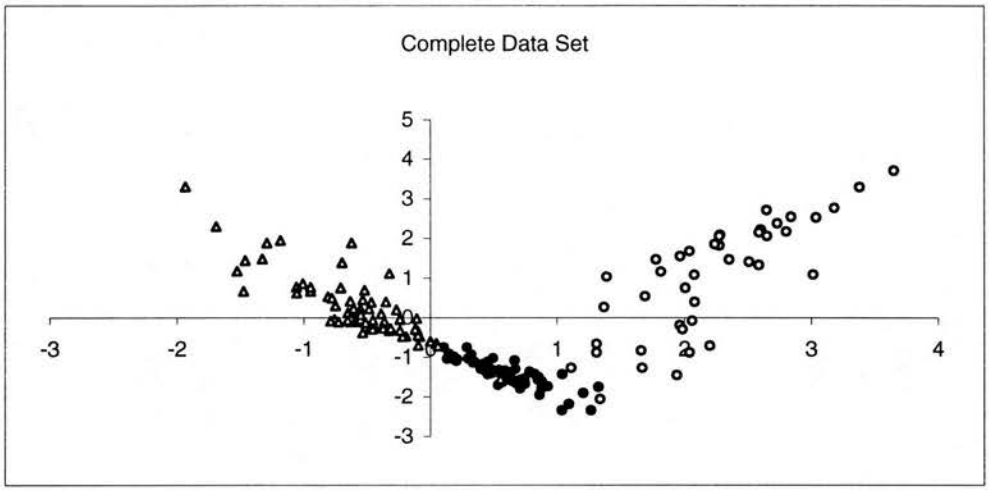


Figure 5.19



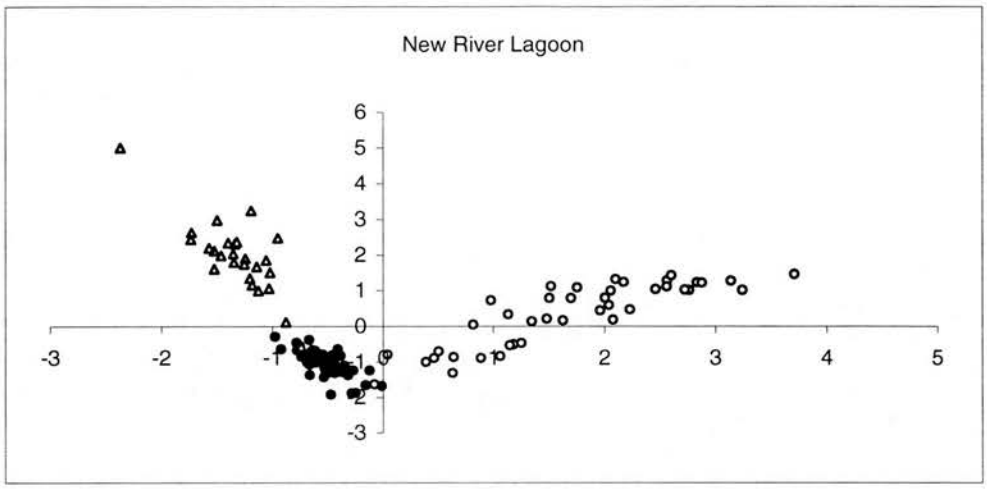
Key: Southern Lagoon, Monkey Tail and Almond Hill (triangle)
Hillbank, Kates Lagoon, Lamanai, Cobweb Swamp, Botes Lagoon and Outpost. these sites are dominated by *Brachysira neoexilis, Navicula radiosa, Mastogloia elliptica* var. *dansei, Denticula elegans* and *Nitzschia amphibia* var. *rostrata* (Closed circle).

Figure 5.20



Key: Modern samples (triangles), Hillbank (filled circles), Lamanai (open circles)
This figure highlights the differences between the three data sets. The Hillbank and modern samples form a continuum and the Lamanai data are much less coherent.

Figure 5.21



Key: Modern Samples (triangle), Hillbank (filled circle), Lamanai (open circle)
Even with the reduced data set all the samples from the New River Lagoon are still distinctly different from one another.

Figure 5.22

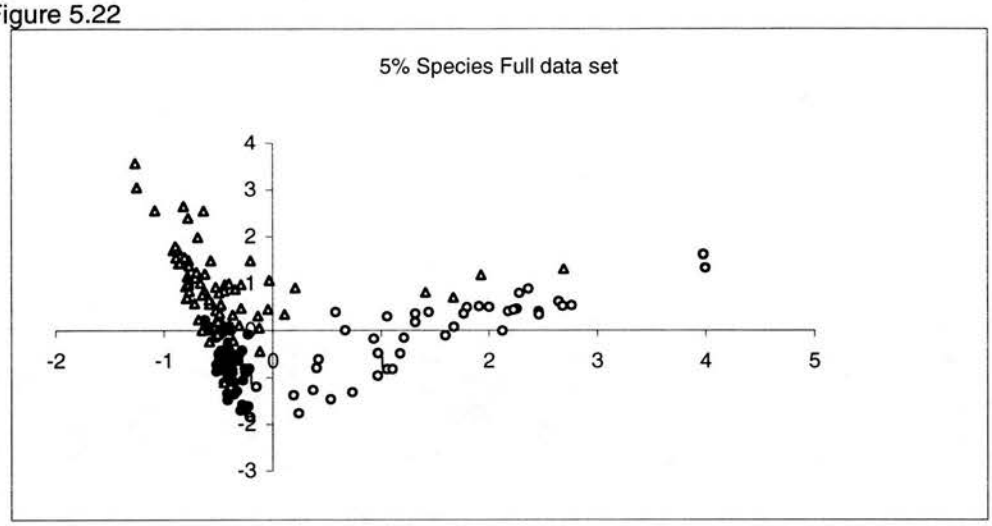
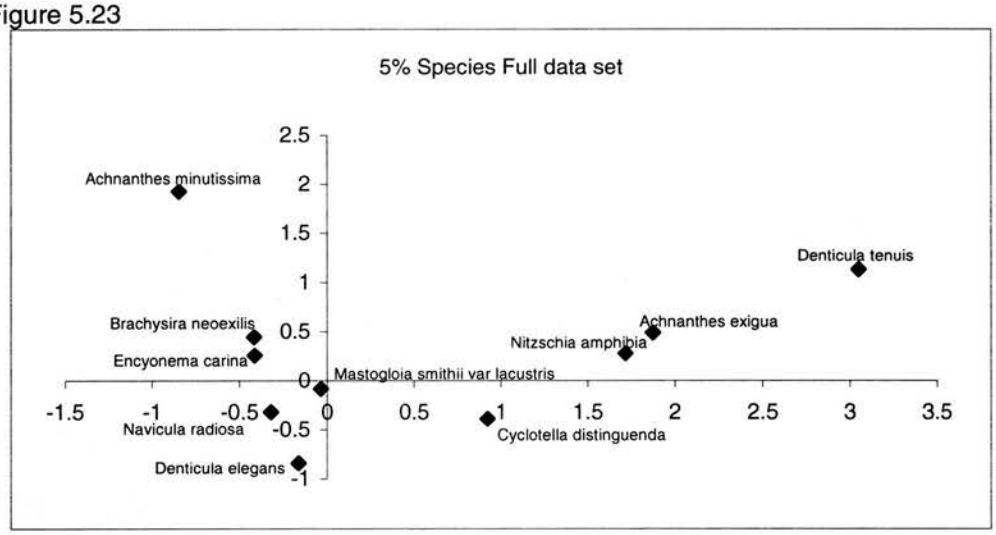


Figure 5.23



Key: Lamanai (circle), Hillbank (filled circle), Modern samples (triangle)
When only the dominant species are considered the data sets are much less coherent, but the modern samples are much more closely related to the core data.

Figure 5.24

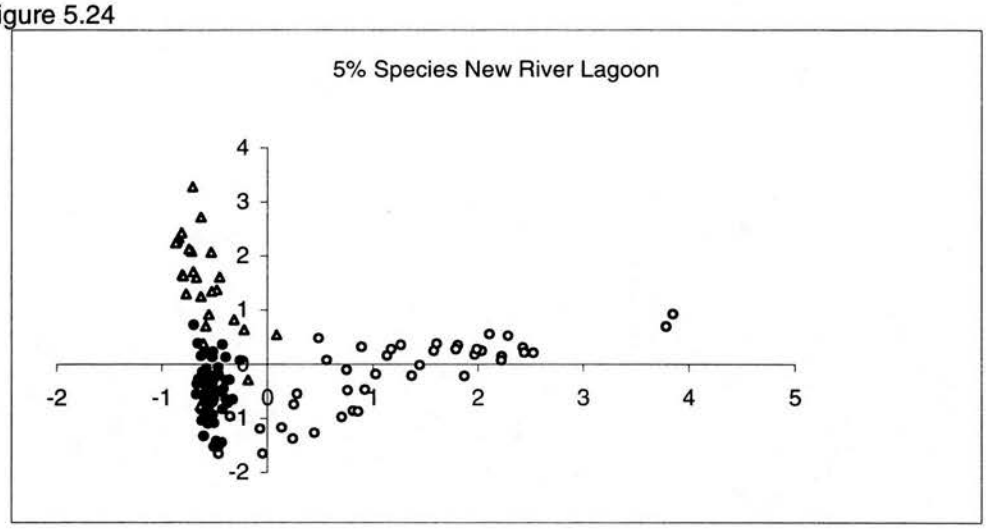
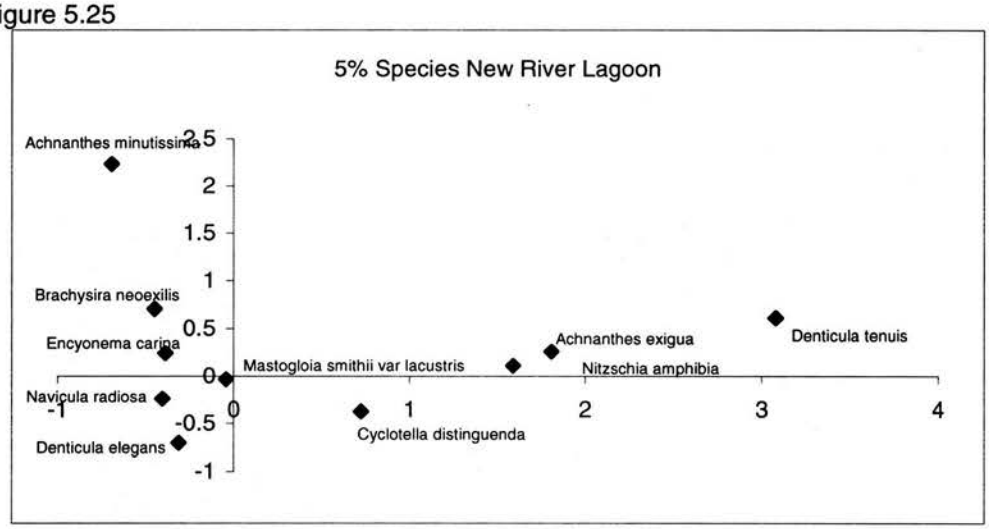


Figure 5.25



Key: Modern samples (triangle), Hillbank (filled circle), Lamanai (circle)
This shows the same sample and species distribution as the full data set.

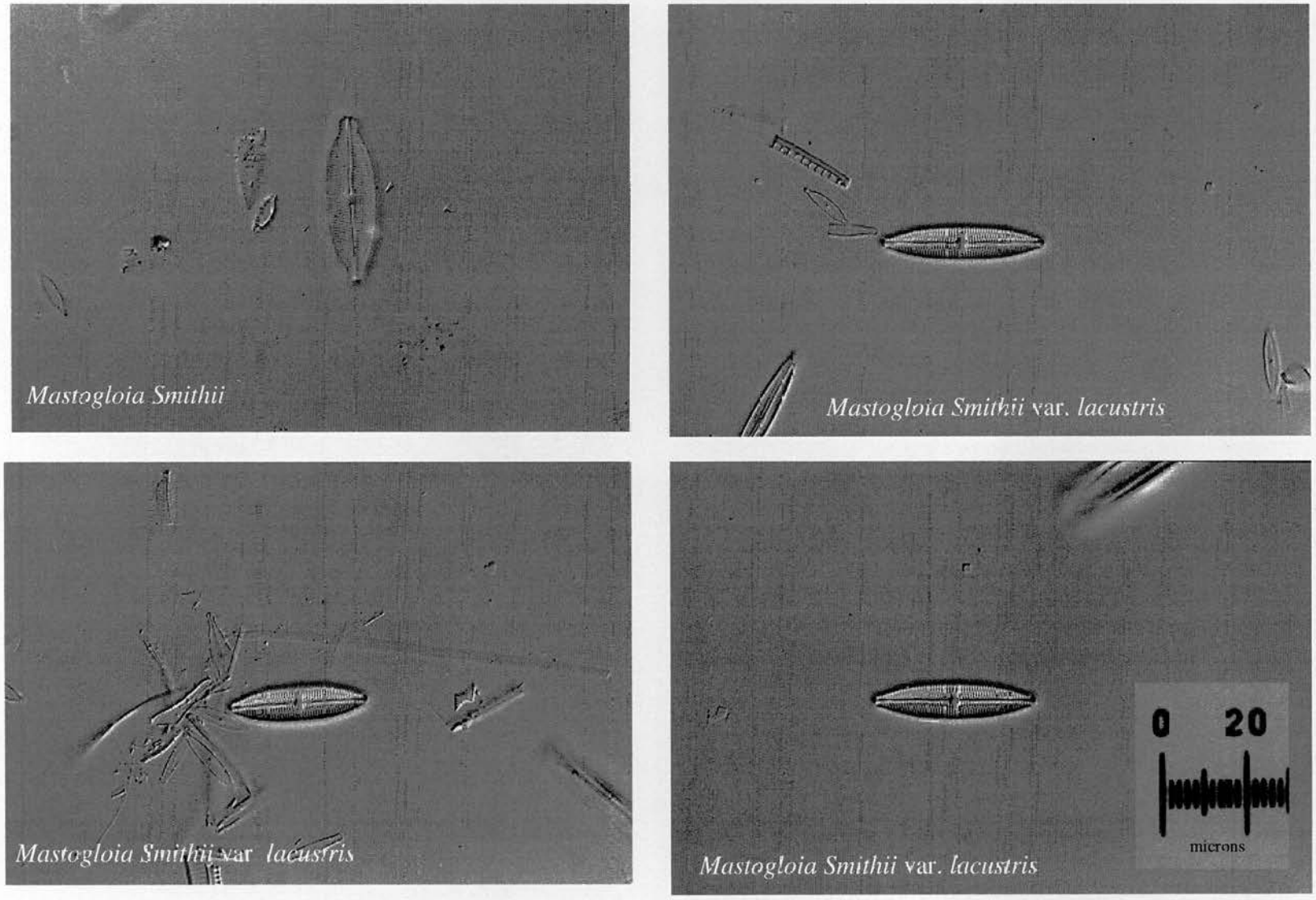
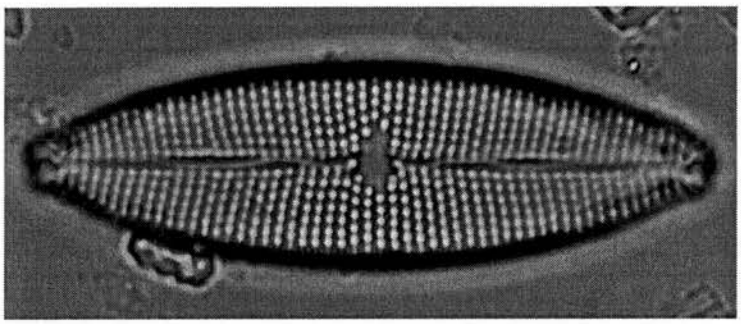
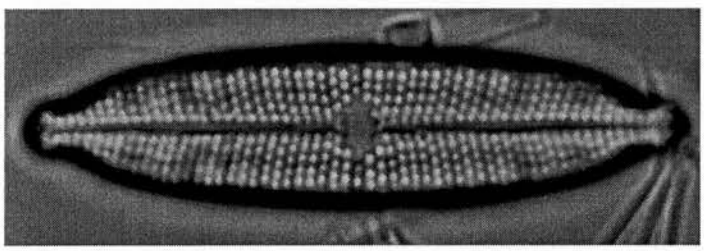


Figure 5.26 Examples of *Mastogloia Smithii* (coll WM Smith BM 24346) and *Mastogloia Smithii* var. *lacustris* (Van Heurck N 47 26358).

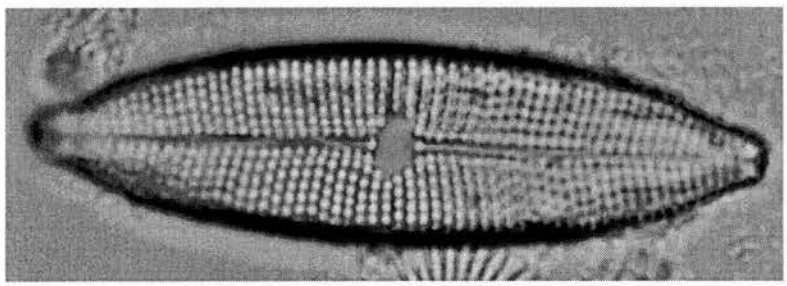
Figure 5.27 Mastogloia smithii var lacustris family, New River Lagoon, Belize



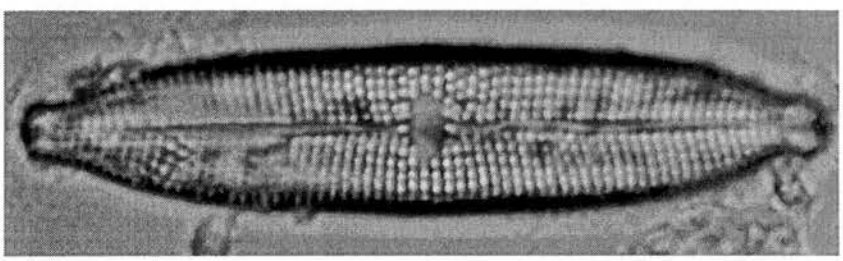
Modern Sediment type



Modern Reeds type

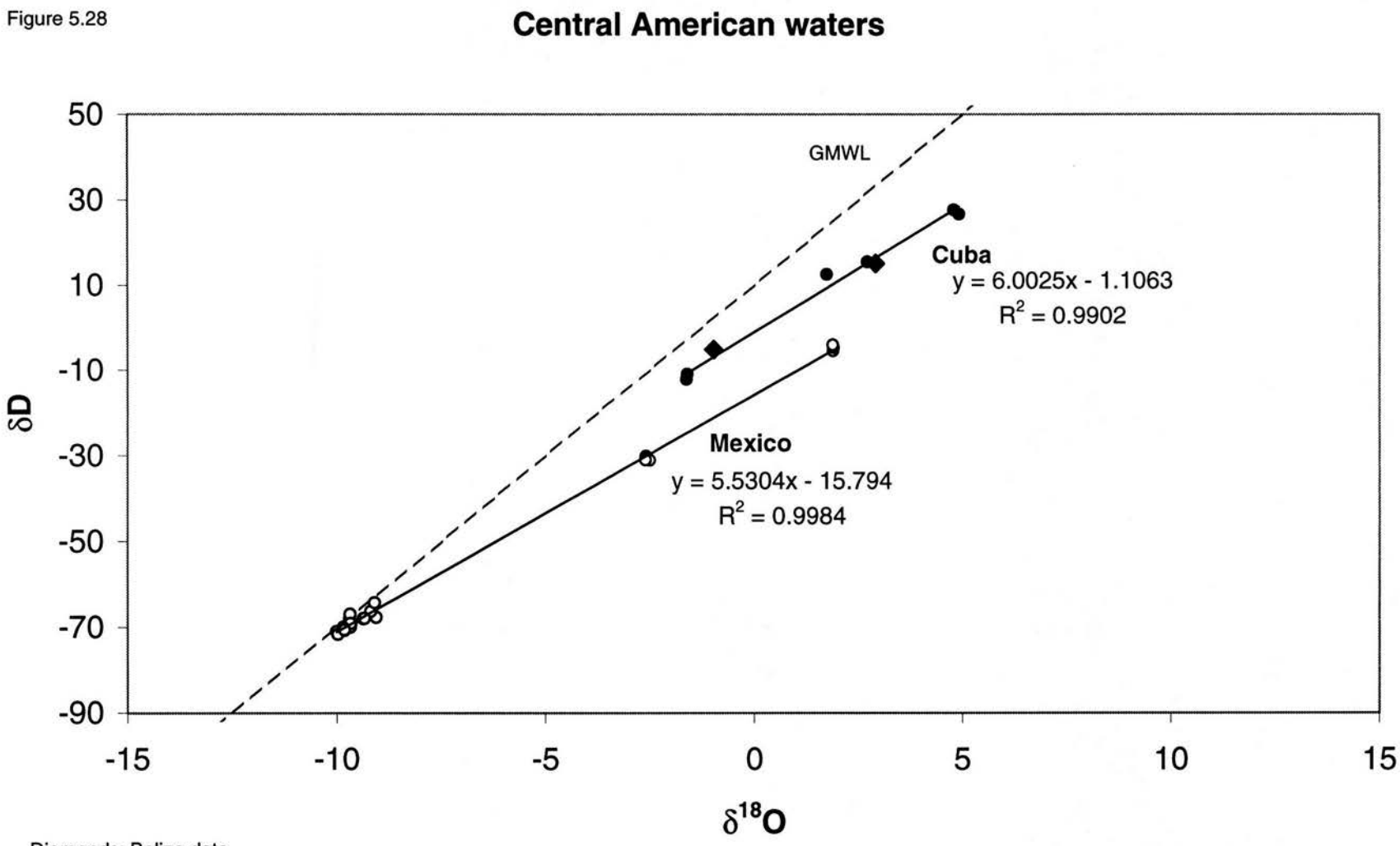


Fossil "Sediment" type (Outpost)



Fossil "Reeds" type (Outpost)

Figure 5.28



Diamonds: Belize data

Chapter Six: The Results from Hillbank, New River Lagoon

6.1 Introduction

The three chapters which follow present the results from the three main coring sites: Hillbank and Lamanai, New River Lagoon and Honey Camp Lagoon. The Hillbank 1998 sequence covers the longest time period and therefore provides a context within which the other records can be placed. The impact of human activity through time is clearest in the Lamanai sequence. Honey Camp Lagoon provides insight into the wider manifestations of environmental change in north Belize.

This chapter presents an analysis of the results gained from the diatom and stable isotope records from Hillbank, New River Lagoon. In order to appreciate both spatial variation and a more complete picture of the lagoon's history, two cores were analysed. These were a 14m Livingstone core from the southern shore and a 69cm Kullenberg core from 6-7 metres of water (Figures 6.1 and 6.2). This information provides a general appreciation of changes over a long time period, an in depth understanding of events in the more recent past, and an idea of spatial variability within this part of the lagoon.

6.2 Hillbank 1998

An earlier study (Breen, 1998) analysed this core for diatoms and a total of 71 depths were counted as part of this joint Natural History Museum and Edinburgh project (Blackmore, unpublished). Subsequently, 58 further depths have been analysed for diatoms and a stable isotope record has been created for the whole core from the analysis of both bulk carbonate and gastropods. The stratigraphy of this core can be found in appendix 6, which includes a key to the symbols shown in the diagrams. The stratigraphy for Hillbank 1998 can only be regarded as preliminary due to the problems highlighted in section 4.3.1.

There are five AMS radiocarbon dates for this sequence:

Table 6.1

Code	Depth (cm)	Material	^{14}C Years BP	$\delta^{13}C_{PDB}‰$ +/- 0.1	Calibrated Ages	2 Sigma range
CAMS -77197	1242	Organic Matter (OM)	9840 +/- 60	-27.6	8778, 8771, 8745 BC	9138-8610 BC
CAMS -45870	990	OM	6020 +/- 50		4909, 4872, 4855 BC	5046-4744 BC
AA-39722	400	OM	130+/-55	-28.0	AD 1689, 1729, 1810, 1922, 1948	AD 1656-1954
AA-39721	153	OM	4752+/- 66	-30.3	3626, 3586, 3527 BC	3655-3367 BC
CAMS -77198	113.5	Gastropod (G)	3990 +/-40	-7.9	/	/
AA-42417	113.5	OM	2463+/-48	-27.6	756, 701, 539, 526, 524 BC	789-402 BC

The hardwater lake error from the paired date at 113.5cm is 1527 years. The difference is a result of the input of old, ^{14}C-deficient carbon into the dissolved inorganic carbon of the lake water (Deevey and Stuiver, 1964). Terrestrial organic material is free from this because it derives its carbon from atmospheric CO_2. The estimated hardwater error for Hillbank fits with published values for Guatemala and the Yucatan Peninsula (Hodell *et al.*, 1991; Leyden *et al.*, 1993; Hodell *et al.*, 1995; Curtis *et al.*, 1996 and Leyden *et al.*, 1998) (see section 4.6.2).

The dates are all in chronological order apart from the one at 400cm. The radiocarbon samples from 990-153cm were taken by the team from the Natural History Museum, London. The author was not involved in these stages and thus the reasons behind the two dates which show a large reversal can only be postulated. There are three possible reasons behind the reversal.

1. Firstly these dates could be correct and the sediment cores (which were taken in one metre sections) could have been incorrectly labelled and the top half of the sequence has in fact been reversed. This is the worst case scenario, as it would completely change the interpretation of the sequence.
2. The radiocarbon samples could have been incorrectly labelled.
3. The sample could be contaminated in some way, for example through the addition of very young carbon.

Due to the coherence of the rest of the dates it is apparent that the date at 400cm, which is anomalously young, should be rejected.

Figure 6.3 shows the dates in stratigraphic context. This shows that there have been three quite different sedimentation rates through time. These vary from 0.066cm/year (9840-6020 ^{14}C years BP) to 0.66 cm/year (6020-4752 ^{14}C years BP) to 0.017cm/year (4752-2463 ^{14}C Years BP). The immediate implication of this is that there is an order of magnitude difference in the rate exhibited in the middle period. This suggests that this was the greatest period of activity in the catchment. Such a finding is in good agreement with the record from Lake Peten-Itza where the mid-Holocene also shows a comparable increase in the sedimentation rate (Curtis *et al.*, 1998). As a result of the changes in sedimentation rate, it would be an unsound strategy to extrapolate dates below 1242cm. The age at the base of the sequence is therefore greater than 9840+/-60 ^{14}C years BP and it is not certain how much sediment is missing from the top of the sequence. In order to calculate the ages of important depths the record was split into three parts and the equation of each line was worked out. From this it was possible to estimate ages in radiocarbon years. These were converted to calendar years using Stuiver and Pearson (1993). The estimated dates are referred to as years BP.

This core was collected as part of a project funded by NERC (GR3/10721) to the Natural History Museum to investigate the vegetational history of Belize through pollen analysis. From this a limited pollen diagram has been produced comprising of 17 depths (Figure 6.4). This record shows that the abundance of pine pollen varies

throughout the profile. This is interesting because today Hillbank is surrounded by pine and palm savanna. It is absent between 200-300cm and abundant from 200cm upwards. *Chenopodiaceae* pollen, which is an indicator of agricultural activity, reaches the peak in its abundance at 220cm. Broadleaf trees are more abundant than pine below 720cm and *Rhizophora* (the dominant genus in mangrove forest) is consistently present below 700cm. There is no evidence for maize pollen in this sequence (Blackmore, unpublished).

6.2.1 The Diatom Record:

The diatom records from the New River Lagoon have been analysed in four stages:

1. The qualitative description/interpretation of the diatom diagram.
2. Dissolution indices were employed on one of the most common species: *Mastgloia smithii* var. *lacustris*. The aim of this was to improve understanding of preservation in the system.
3. The diversity and concentration of diatom species at each level was calculated.
4. The transfer function created by Reed (1995, 1998a) was employed. This reconstructs conductivity drawing on a data set from Spain. This was deemed to be more suitable than the data sets from East Africa (Gasse *et al.*, 1995) and Central Mexico (Davies *et al.*, in press) because it contained the most species in common with the Belizian data sets. Table 5.2 highlighted the differences between the reconstructed conductivities for key species in Belize and Spain. This must therefore be taken into consideration when interpreting these results.

The record from Hillbank has a very uniform diatom flora and there are no dramatic shifts in the species that are present (Figure 6.3). The key periods of change are those where diatoms are not preserved. All the species mentioned are pictured in appendix 2. The record can be split into 6 zones according to changes in the main diatom flora:

Zone 1 - 1381-1300cm:

This zone is dominated by *Denticula elegans*, *Mastgloia smithii* var. *lacustris*, *Encyonema carina*, *Brachysira neoexilis* and *Navicula radiosa*. There are also small numbers of *Mastogloia smithii*, *Cyclotella plitvicensis*, *Navicula pupula*, *Navicula radiosa* var. *tenella*, *Nitzschia amphibia* var. *rostrata* and *Achnanthes minutissima*. There are no shifts between these species which suggests that this was a very stable period in the lagoon's history. These species are all littoral (Gasse, 1986; Krammer and Lange-Bertalot, 1986; 1988; 1991a and 1991b). The ecology of *Cyclotella plitvicensis* is unknown and it does not occur in any of the modern samples collected in Belize. This species is noted in the literature as often being confused with *Cyclotella distinguenda*. This is discussed in more detail in appendix 7. This assemblage without *C. plitvicensis* is found in Kates Lagoon, Lamanai and Hillbank sediment samples all of which are highly vegetated sites (Figure 4.1). The gap at the top of this zone is because sediment was not available to sample.

Zone 2 - 1300-1200m:

This is the most unusual zone in the whole sequence. It is barren of diatoms (signified by the dashed lines) apart from two layers. In these two layers only 200 diatoms were counted and therefore the description of these layers can only be regarded as preliminary. *Aulacoseira granulata* and its varieties, *Denticula elegans*, *Mastogloia smithii* var. *lacustris*, *Encyonema carina* and *Brachysira neoexilis* dominate the layers. *Aulacoseira granulata* is found in two modern day samples from Belize, in the Booth River wetlands and Chiwa Lagoon and these environments are both swamps (Figure 4.1). *A. granulata* is usually found in warm, nutrient rich, turbid conditions (Gasse, 1986). The rest of the species that are found in this zone have already been found in the sequence, which suggests that conditions have not changed as much as it might first appear. What is significant is that the species appear during a time of poor diatom preservation suggesting that the system is undergoing change.

Zone 3 - 1200-950cm:

The gap at the beginning of this zone is because sediment was not available to sample. This zone is dominated by the same species that are found in zone 1, with the additions of very low levels of *Cyclotella distinguenda*, *Cymbella muellerii* and *Mastogloia elliptica* var. *dansei*. The slight increase in diversity suggests that the environment has now become more amenable to a broader sweep of species. There is very little trend to this zone apart from a general decline in the levels of *Denticula elegans* while levels of *Navicula radiosa* and *Achnanthes minutissima* increase. *Mastogloia smithii* is not common to modern samples but the main suite of species are found in Kates, Lamanai and Hillbank which are the same sites associated with zone 1 (Figure 4.1).

Zone 4 - 950-720cm:

The same species are present in this zone and *Denticula elegans* dominates. There are relatively more *Brachysira neoexilis* than *Mastogloia smithii* var. *lacustris* suggesting that conditions have changed slightly to favour the increase in *Brachysira neoexilis*. The sites that have a similar diatom flora in the modern environment are Hillbank 2 and 2B sediment, neither of these sites is dominated by vegetation and both have conductivities of 1.29 mS cm^{-1} which indicates that these sites are freshwater (Figure 5.4).

Zone 5 - 720-280cm:

A reciprocal relationship occurs within this zone between *Denticula elegans* and *Mastogloia smithii* var. *lacustris* whereby in the centre of the zone when *Denticula elegans* declines, *Mastogloia smithii* var. *lacustris* increases. This highlights what seems to be the pattern for this part of the lagoon - the shift between species rather than the replacement of one with another. This suggests that the diatom record is a reflection of changes to the lake shore rather than wider changes to the catchment. The levels of *Brachysira neoexilis* drop in this zone while levels of *Encyonema carina* remain high. Species such as *Navicula radiosa* and *Mastogloia smithii* are very consistent throughout the whole record which suggests that these species are less sensitive to change than others. The sites in the modern environment which

have more *M. smithii* var. *lacustris* than *D. elegans* are Doubloon Lagoon (epiphyte), Kates Lagoon (sediment) and Hillbank 1 (epiphyte) all these samples are from highly vegetated zones and low conductivities ranging from 0.23-1.48 mS cm^{-1} (Figures 4.1 and 5.4).

Zone 6 - 280-0cm:

This zone is punctuated by three zones that are barren of diatoms. The depths which have preserved diatoms each have the same species present which suggests that the system is fluctuating between two states. This implies that the lagoon is on the cusp of preservation and therefore it is not wider scale changes that are causing the lack of diatom preservation but small shifts to the chemical and physical environment of the New River Lagoon which enable the preservation of diatoms. The key shift in diatom species which is seen in this uppermost zone is the dominance of *Denticula elegans*, *Encyonema carina* and *Mastogloia smithii* var. *lacustris* in the central zone to *Mastogloia smithii* var. *lacustris*, *Brachysira neoexilis*, *Denticula elegans* and *Nitzschia amphibia* var. *rostrata* in the top section. These species are rather stable and therefore the shift is really once again between a *Denticula elegans* dominated environment to a *Mastogloia smithii* var. *lacustris* one. In terms of the environment this may involve a shift from higher to lower conductivities with an increase in the size and domination of vegetation.

The dissolution indices highlight that the story for Hillbank is more complicated than would first appear (Figure 6.6). The main section of this record is a long period of diatom preservation (zones 3-5). The results of the DDI highlight that there is a great deal of variability in the conditions of the *Mastogloia smithii* var. *lacustris* through this period. The DDI index records a value of zero if there are no perfectly preserved diatoms in a sample. This means that information is lost because a value of zero implies that there are no *Mastogloia smithii* var. *lacustris* present, but there could be high numbers of specimens preserved at stages 2,3 and 4. The WI indices show that through zones 3-5 *Mastogloia smithii* var. *lacustris* is present. Preservation appears to switch between two states suggesting that preservation is not the natural state for the system. The key point that the indices highlight is that although diatoms are

found throughout zones 3-5 they are being influenced by forcing factors which affect their presence. Thus a seemingly stable part of the record is actually quite variable.

Poor preservation is a phenomenon across Belize with all the other lagoons cored for this investigation failing to have diatoms preserved within them (see Chapter 4 for more details). There is also a good match between the number of diatoms in the sediment and the preservation levels, i.e. where there are a lot of diatoms they are well preserved. The average diversity of species for the Hillbank sequence is 13 (Figure 6.7). The average for the main section of the record is 16 species, which is slightly higher suggesting that during this time period conditions were more favourable to the preservation of greater range of diatoms.

The reconstruction of conductivity (using Reed's 1995 Spanish transfer function) in the Hillbank sequence showed that the average conductivity for the record is 3.3 mS cm^{-1} (Figure 6.5). The value for each zone is:

1. Zone 1: 2.8 mS cm^{-1}
2. Zone 2: no data
3. Zone 3: 2.7 mS cm^{-1}
4. Zone 4: 3.3 mS cm^{-1}
5. Zone 5: 3.4 mS cm^{-1}
6. Zone 6: 3.5 mS cm^{-1}

It would appear that there is a division in the record between zones 1-3 and 4-7 with the first zones having a lower reconstructed salinity than the top zones. This highlights that although there have not been any key changes in the flora, the relative changes in species abundance are significant.

The second point is that the reconstructed conductivity values for the core data are much higher than the modern values for Hillbank (1.12-1.29 mS cm^{-1}) and are more similar to Caledonia, New River (3.54 mS cm^{-1}) (Figure 4.2). This site is located further down the New River and is therefore much more likely to be influenced by

the sea than the lagoon. The difference between the reconstructed core values and the modern day conditions could be the result of several reasons:

1. The date for the top of the Hillbank sequence is not known and therefore conditions could have been different from those of the present day. This is compounded by the fact that the modern day assemblages in Hillbank are not exactly the same as those found in the core.
2. The conductivity range for the species found in the core is different in Spain and Belize.
3. The diatom species found in the core may not have been living in their optimum conductivity conditions through time in Hillbank. This may be because conductivity is not the most influential factor with regard to species distribution in the New River Lagoon.
4. The diatom species found in the core have wide tolerances.

These points highlight the importance of creating transfer functions from the study area so that firm conclusions can be made with regard to species tolerances and optimum conditions. Through the work completed in this investigation on the modern diatom flora (Chapter 5), it is apparent that habitat is of key importance in differentiating the diatom flora of New River Lagoon and therefore conductivity may not be so influential. Chapter 4 emphasised the importance of geographical location as a factor which influences species distribution and also the issue that species may evolve to inhabit different physical and chemical environments in different areas.

To summarise, the diatom record reflects subtle changes in conductivity and vegetation in a littoral record. Zone 1 (1381-1300cm) reflects medium conductivity (2.8 mS cm $^{-1}$) and well vegetated conditions, zone 2 (1300-1200cm) seems to indicate a drop in water levels with swamp-like conditions persisting. More detailed information would need to be collected on *Aulacoseira granulata* to verify this. Conditions revert back to those in zone 1 in zone 3 (1200-950cm). From 950-720cm (zone 4) conductivity levels are increase to 3.3 mS cm^{-1} and vegetation levels drop. The opposite conditions occur in zone 5 (720-280cm) although conductivity values remain high. In zone 6 conditions shift from a *Denticula elegans* dominated system

(150-90 cm) to a *Mastogloia smithii* var. *lacustris* dominated system. The reconstructed salinities move from 3.2 to 4.2 mS cm^{-1}. This increase is likely to be influenced by the increase in *Nitzschia amphibia* var. *rostrata* and *Brachysira neoexilis* at the top of the record.

A DCA analysis was undertaken to enable the associations and differences between species and depths to be quantified. The eigenvalues are however extremely low at 0.135 and 0.1. This implies that the axes do not explain the associations seen in the core. This may be a function of the limited variation in the data set which is signified by the short axes. The graphs (Figure 6.8) both show scatter, suggesting that the differences between depths are shifts in the dominance of species rather than completely new assemblages. Such an interpretation is in agreement with the qualitative analysis of the diatom record.

6.2.2 The Stable Isotope Record:

Oxygen and carbon were measured on both bulk carbonates and three species of gastropods (*Cochliopina*, *Pygophorus* and an unidentified species). 54 samples have been measured, approximately every 10 to 20cm. The sampling resolution was constrained by the availability of material due to the missing core sections.

The oxygen isotope record has three main episodes of change at the beginning, middle and end of the sequence (Figure 6.9). The conditions represented by the isotopes are most different at the inception of the record. At the beginning of the oxygen isotope record conditions are very unstable with values shifting from -3.7 ‰ to -0.5 ‰. This suggests that the system was responding to large, but short lived, forcing events. Values then have a more sustained excursion from 1287-1248cm where the least negative isotope values for the whole sequence are found. These are approximately 3‰ higher than the mean value of the sequence. This is a highly significant difference. Values return to stable conditions by 1198cm and are maintained at around -3.5 ‰ until 630cm. This depth is the peak of a negative excursion where values reach -4.12 ‰. A shift occurs at 378.5cm where values

remain stable, but are less negative than in the previous phase (584-378.5cm (average) = -3.6 ‰, 338.5-203cm (average) = -3.3 ‰). Conditions then remain stable until 193cm. This is the beginning of a very variable period where values oscillate to the top of the sequence. The level of fluctuation is not high but the values are more negative in this transitional phase than at any point previously encountered in the record. The level of variation is also the largest in the sequence with the exception of the base of the record.

Gastropods have also been measured from this sequence (although at a much lower resolution) (Figure 6.9). The record from *Cochliopina* sp compares well with the bulk carbonate record showing the large swings at the base of the record, stability through the main section of the record with values centring around -3.5 ‰ and greater variability at the top of the sequence. Measurements were also taken from *Pygophorus* sp and an unidentified sp. The *Cochliopina* and *Pygophorus* sp match well. The unidentified sp shows a great deal more variation at the top of the record. This could be because the habitat which this species occupies is different from that of *Cochliopina* and *Pygophorus* sp which occupy similar areas (see Chapter 4 for details).

The bulk carbonate results for the carbon isotopes show the same four zones of change as the oxygen isotope record (Base-1198cm, 1198-584cm, 584-378.5cm, 378.5-203cm and 203-0cm) but the shifts that are seen at the top of the sequence are of a greater magnitude (Figure 6.10). From the base of the record to 1248cm the $\delta^{13}C$ values are stable at around -2.5 ‰. This suggests that even though the $\delta^{18}O$ record is very variable the inputs of carbon to the system are very stable. The system then undergoes a rapid change with the isotopes recording the most negative peak in the record at 1208cm at -8.1 ‰. The $\delta^{13}C$ values increase after this point and become much more stable. Fluctuations are minor until 666 to 584cm. This is a period of change in the system which coincides with the negative excursion in the $\delta^{18}O$ record. At this time the $\delta^{13}C$ records increase and then at 630cm levels drop. Levels then stabilise at around -2.9 ‰. From 338.5cm values begin to decline but this is a time of very gradual change which again coincides with the $\delta^{18}O$ record. From 193cm

onwards the carbon isotopes record rapid changes suggesting that the system is now operating in a very different way to the past.

The carbon isotope gastropod record does not relate as well to the bulk carbonate record as it does for the oxygen isotope sequence (Figure 6.10). The trends between the species are the same though, with *Cochliopina* sp and *Pygophorus* sp being similar in their magnitude and the unidentified species being both different and exhibiting larger variations in isotopic values.

In interpreting the records one needs to be aware that the two isotopes could be telling different stories because the New River Lagoon is an open system. This is highlighted by a scatter plot of $\delta^{18}O$ versus $\delta^{13}C$ which shows that the system does not exhibit covariance (Figure 6.11).

6.3 Preliminary Interpretation:

Of principal importance is the determination of the main driving forces behind the system, i.e. whether they are catchment- or within-lake processes. The New River Lagoon is a large open system which eventually connects to the sea via the New River. It is therefore under the influence of not only climatic change but also groundwater and catchment variations, which are likely to have more influence on the isotopic signature because of the open nature of the system.

The isotope zones which have been identified date to:

- >9840+/- 60 – 9200 years BP
- 9200-5400 years BP
- 5400-5100 years BP
- 5100-4800 years BP
- 4800 years BP –top

Freshwater gastropods and diatoms are present to the base of the Hillbank sequence which implies that the system has held permanent water throughout. The Hillbank

record reaches its most positive $\delta^{18}O$ values between 1278 and 1248cm i.e. in the immediate period before 9840+/- 60 ^{14}C years BP. This is also a time of change in the diatom flora. Although the shift in the Hillbank record looks dramatic it actually occurred over a period of approximately 1000 years with the system reaching almost average conditions by 1228cm or c. 9600 years BP. The climate of Central America was dry in the Lateglacial and moist during the early to mid Holocene periods (Leyden *et al.*, 1994). The record from Hillbank suggests that the Lateglacial was a very variable period and that conditions in the time period immediately before the Holocene were very different from the rest of the sequence. Total carbonate has also been measured on this sequence (Figure 6.12). This shows uniformly high levels throughout apart from at the base of the record where values drop to 55%. This matches the magnetic susceptibility record well (Figure 6.12). The period of highest levels and therefore a period of disturbance and changing inputs into the system is at the base of the record. This time period is therefore one of significant change. It is possible that this period equates to the Younger Dryas. If this is the case then the signal for Belize at this time is a dry climate.

The transition to wetter conditions was very smooth and this implies that there was a clear climatic difference between the Lateglacial and early Holocene in Belize. The transition to full moist conditions was completed by c. 9600 years BP. Conditions remain stable and moist until 666cm or 5500 years BP. From this point until 584cm or c. 5381 years BP there is a negative excursion in the $\delta^{18}O$ record. This is a fairly short-lived event that coincides with a change in the $\delta^{13}C$ record. This suggests that it is a period of catchment disturbance with low $\delta^{18}O$ values occurring at a time of enhanced $\delta^{13}C$values. The $\delta^{18}O$ record continues to be stable and moist with a shift occurring at 378.5cm or c. 5100 years BP to slightly less negative values. At c. 4800 years BP or 193cm the $\delta^{18}O$ record becomes more variable. The shift in the isotope record from a stable to a variable signal from this point suggests that this is the beginning of a new phase of environmental change in the region.

122cm equates to approximately 3000 years BP and is the end of the negative excursion in the $\delta^{18}O$ record. This is generally considered to be the end of the mid

Holocene moist period in the circum-Caribbean (Hodell *et al.*, 1991). The late Holocene dry period occurred between 1300 to 1100 ^{14}C years BP. Due to the lack of knowledge concerning the sedimentation rates it would be unwise to postulate where this time period might fall on the Hillbank record. Although levels of $\delta^{18}O$ do become more positive, a distinct and severe arid period is not recorded in the Hillbank oxygen isotope record. It cannot however be guaranteed that the top of the record covers this event. It is possible that the large nature of the New River Lagoon renders it insensitive to short-lived events such as the late Holocene dry period. A further possibility is that north Belize was not affected by this event.

The carbon record provides a good complementary record to the oxygen sequence. The base of the record is characterised by stable, but increasingly positive levels of $\delta^{13}C$. This is likely to be a result of the relative proportion of DIC coming from the dissolution of limestone versus equilibration with atmospheric CO_2. During this period the $\delta^{18}O$ record is moving towards the most positive values in the sequence. This shows good agreement between the two records with exchange with atmospheric CO_2 becoming the dominant process in this increasingly shallow system.

The large negative excursion which follows this, reaches a peak at 1208cm (c. 9300 years BP) which is when the transition to full moist conditions in the $\delta^{18}O$ record occurred. As the climate was becoming wetter, the $\delta^{13}C$ record became more negative. There are a number of reasons why the carbon record would be showing this signal:

1. Influx of freshwater in the system (influencing exchange with atmospheric CO_2) which would equate to the negative conditions shown in the $\delta^{18}O$ record.
2. The oxidation of organic matter. It is during this time period that lowland forest became established in Guatemala (Leyden *et al.*, 1993) which suggests that the input of terrestrial organic matter into the catchment would have shifted to much more negative values (C4 plants = -12‰; C3 plants = -25‰) (Curtis *et al.*, 1998). The oxidation of terrestrial organic matter generates CO_2 that has an isotopic signature similar to the source material, some of which can dissolve into

groundwater and reach the lake, influencing the signature of the lake water DIC. In addition, oxidation of allochthonous organic matter within the lake produces CO_2 which has an isotopic signature that also reflects the source material and this CO_2 influences the isotope ratio of the DIC (Curtis *et al.*, 1998). If this signal is the transition to a forested catchment then it occurred approximately over a thousand year period.

The negative peak in the $\delta^{13}C$ record coincides with an interesting change to the diatom flora. It occurs during a phase of poor diatom preservation and the introduction of the diatom species *Aulacoseira granulata*. This species is found in the plankton of shallow lakes. Although the other species found in this part of the sequence are common throughout the record the introduction of this species suggests that this is a period of environmental change. This is compounded by the fact that such a change in the diatom flora or the $\delta^{13}C$ record is not found at any other part of the record.

Levels of $\delta^{13}C$ rapidly increase reaching a steady state by 1048cm or c. 6887 years BP. It is unlikely that the forest taxa would have disappeared and therefore the increase in $\delta^{13}C$ is likely to be due to a shift in the inputs into the system. This is the beginning of a more stable phase of diatom preservation suggesting that the environmental conditions have changed because diatom preservation is now continuous. With the moist conditions of the early Holocene, aquatic photosynthesis would have been high and therefore the $\delta^{13}C$ levels would have increased correspondingly.

Values of $\delta^{13}C$ are fairly stable through the Holocene suggesting a productive lake which exists in stable climatic conditions. There is a negative excursion in the $\delta^{18}O$ record which peaks at c. 5450 years BP. The relationship between the two isotopes is not simple. Although levels of $\delta^{13}C$ do increase they drop at the peak of the $\delta^{18}O$ excursion. This suggests that there is an interplay in the $\delta^{13}C$ record between the influence of freshwater inputs (negative excursion) and the role/magnitude of aquatic photosynthesis (positive excursion).

The $\delta^{13}C$ record begins a negative trend at c. 5000 years BP which is where the shift to more positive values in the $\delta^{18}O$ record begin. The carbon record highlights a time of significant change to the system between 193-152cm or c. 4790-4750 years BP. The pollen data (Figure 6.4) for this period show a peak in Chenopodiaceae pollen which is an indicator of disturbance. This suggests that it may be during this time frame that the area around Hillbank began to be first disturbed by human activity. This is not enough evidence to make this claim but it is possible because during this phase of Mayan history sedentary agriculture is thought to have begun in Belize (Hammond, 1982). This time period is also one of increasingly negative $\delta^{18}O$ values, reaching values akin to those found at 630cm. Rosenmeier *et al.* (in press) looked at the $\delta^{18}O$ record for Lake Salpeten and related the changes in this isotope to variations in the forest cover of the lake catchment. Decreased values were associated with times of forest loss, as a result of greater surface runoff and groundwater inflow to the lake. This therefore adds weight to the argument that this is the time period when human activity is prevalent.

Hansen (1990) documents dramatic deforestation in Albion Island, Belize around 2800 ^{14}C years BP which equates to approximately 120cm. This is not a clear period of change in the Hillbank pollen diagram (Figure 6.4) but it is difficult to be certain because the top of the record is missing. This period occurred during a positive shift in the $\delta^{13}C$ record which suggests that this a highly productive phase and the catchment is being increasingly deforested. The $\delta^{18}O$ values are also recording a positive trend. If deforestation was the main control over the system at this point the $\delta^{18}O$ signal would be negative (following the arguments of Roseinmeier *et al.*, in press) which suggests that further climatic changes are occurring at this point in the sequence. The negative shift of the carbon isotopes from 60cm to the top of the record could represent forest recovery.

How do the isotope and diatom data relate to one another? The diatom record is a reflection of changes to habitat availability and changes in conductivity. The changes that the record represents are not major but there are interesting links between the two sequences. The first is that the periods where diatoms are not

preserved equate to the most variable times in the isotope record (1201-1288, 214-260, 152-193 and 22-80 cm). This implies that the lack of diatom preservation is symptomatic of a change to the environment of the lagoon. The periods where diatoms are not preserved coincide with periods of decreasing $\delta^{13}C$. This could be a result of lower inputs into the system due to forest cover in the catchment, an increase in the oxidation of organic matter or fluxes of freshwater. All of these processes are likely to affect both the chemistry and physical make-up of the system.

The percentage of calcium carbonate present in the core (Figure 6.12) only drops during the 1200-1300m phase which suggests that this period has different causal mechanisms or is more severe than the changes at the top of the sequence. This is not surprising because the changes at the base of the sequence are most likely due to changing inputs into the lake as a result of the climatic changes associated with the end of the Lateglacial and the beginning of the early Holocene. The isotopic changes to the top of the sequence are of a smaller magnitude and the inputs into the system have not changed.

6.4 Hillbank 2000

The location of this core (500 m from Hillbank 1998) is shown on Figure 6.1. This core was analysed for oxygen and carbon isotopes using both bulk carbonates and the gastropod *Cochliopina* sp. This is a 69cm record which was collected using a Kullenberg corer and was analysed every 1-5cm. The stratigraphy for the core can be found in appendix 6. The core was dated using ^{210}Pb. This was the only core suitable for this method due to the insufficient levels of ^{210}Pb in the other Kullenberg records (Outpost 2000 and Honey Camp 2000). The analysis of these data (Figure 6.13) shows that the sediment in the New River Lagoon system is highly mixed because the levels of ^{210}Pb do not decay exponentially. Consequently, the only approximate point of reference is the date of AD 1960 at 12cm because this is where ^{137}Cs can be first picked up in the record (see Chapter 4).

Although the oxygen isotope record is stable, there are definite trends to the data set (Figure 6.14). There are three negative excursions at 65cm, at 27cm and at 17cm with a slight positive excursion at 55cm. This, however, is very short-lived. The gastropod data from *Cochliopina* sp. are limited but provide a fairly good match to the bulk carbonate record apart from at 20cm and 64cm. The difference between the two results is not systematic and therefore it is difficult to draw any firm conclusions as to why this might be the case. The most likely explanation is the role of habitat in influencing the isotopic signature found in gastropod shells.

The $\delta^{13}C$ values follow a negative trend from the base of the record to 33cm (Figure 6.14). The trend from the base to 33cm is gradual, but between 61-53cm there is a negative excursion where values reach a maximum of -9.57‰. The lowest $\delta^{13}C$ values are found at 33cm where they reach -10.03‰. This suggests that it is the oxidation of organic matter that is providing the largest input to the DIC pool. Conditions are rapidly reversed with the most 'positive' values of the record being found at 27cm at -5.05‰. After a reversal of this trend, the record from 21cm to 0cm is stable at around -6‰. The gastropod carbon isotope data matches the bulk carbonate data well in the first half of the record. The most recent gastropod data point is quite different from the bulk carbonate record. This could be a result of a number of factors including a change in carbon source.

The percentage of calcium carbonate that is present in the Hillbank 2000 core can be separated into distinct zones (Figure 6.15). From the base of the record to 61cm the levels are steady at 80%, these then rapidly drop at 57cm to 47%. Conditions then revert back to the original state until 25cm where they drop again to 33%. Levels are then steady at 40-50% from 21cm to the top of the record. The two periods where levels of calcium carbonate drop are short lived, but they do represent a significant change to the inputs into the system.

Magnetic susceptibility has also been measured on this core (Figure 6.15). The measurements were taken using a loop sensor and a mass specific technique. Both these records show the same pattern. Levels are stable and negative from the base of

the record to 32cm. From this point levels begin to rapidly increase reaching a maximum at 25cm. Levels begin to decline just as quickly as they rose and by 15cm the system had stabilised again. This suggests that the peak at 25cm represents a very significant change in the catchment. There are no mass specific results for the top of the core because all the material was used for ^{210}Pb dating.

6.4.1 Preliminary Analysis:

A scatter plot of $\delta^{18}O$ versus $\delta^{13}C$ was undertaken for Hillbank 2000 (Figure 6.11). This shows a fairly coherent cluster of results but these are within a different zone from Hillbank 1998. This suggests that the controlling mechanisms over the New River Lagoon system have changed through time. The trend at the top of the Hillbank 1998 $\delta^{13}C$ record is towards more negative values reaching -5.35‰ at the top of the sequence. The base of Hillbank 2000 is -4.43‰ which is further evidence that the two records are definitely representing different phases of the history of Hillbank. The low $\delta^{13}C$ values exhibited throughout the Hillbank 2000 core may be the result of its location. Hillbank 1998 was taken from the lagoon edge next to the extensive marsh system. Hillbank 2000 was from nearer the centre of the lagoon (in 6-7m of water) and therefore not so influenced by the marsh system. Aquatic photosynthesis enriches the TDIC pool and this is likely to be a much more prevalent process near the marsh system. This may therefore account for the more 'positive' values seen in Hillbank 1998.

There are very low levels of diatoms in the Hillbank 2000 core and as a result a diagram has not been produced. The two species that 'dominate' the assemblages are *Nitzschia amphibia* var. *rostrata* and *Mastogloia smithii* var. *lacustris*. These are present episodically through the top 24cm of the record but not below this point. The appearance of these two species suggests that these must be very robust species that are able to persist in conditions that are obviously not suitable for the vast majority of species that are present in later New River Lagoon sequences.

The levels of magnetic susceptibility are low in this system (Figure 6.15). This is not unexpected because calcium carbonate gives weak or negative values of magnetic susceptibility. At 25cm there is a drop in carbonate levels which is coupled with an increase in magnetic susceptibilty implying that this is a time of significant catchment disturbance. The XRD results for Hillbank 2000 show that during the peak in magnetic susceptibility there is a change in the systems mineralogy, namely with the introduction of quartz, pyrite, dolomite and smectite (Figure 6.16). It is the latter three minerals that are more magnetic than calcite (the dominant mineral), especially pyrite. It is apparent therefore that the peak in magnetic susceptibility is due to the influx of clays into the lagoon. This influx of clays is most likely the result of catchment disturbance and represents a very significant disruption because it is an order of magnitude higher than anything else in the record. During this period there is a peak in the $\delta^{13}C$ values which can imply deforestation. It is therefore postulated that this time period is when colonial logging was at its peak. If 12cm is equal to 1960 that means that 40 years has accumulated in 12cm therefore the period of disruption between 31-25cm is approximately equal to 1897-1917 i.e. the peak of colonial logging.

The ^{210}Pb record does not show a general decline in the levels of ^{210}Pb through time (Figure 6.13). This suggests that this is a highly mixed system. The main implication of this is that the records produced from this lagoon will be an average of the actual conditions experienced and thus signals will not be as strong as conditions at the time warranted. Thus, the changes that are seen in the record must be judged to be very significant as they are likely to be an understatement of the actual magnitude of change. The mixing regime which has been highlighted at Hillbank is unlikely to be unique to that area and it therefore should be taken into account when studying the records from Lamanai.

6.5 Summary of Hillbank, New River Lagoon

From this investigation of Hillbank a number of key conclusions can be made:

1. The oxygen isotope record shows that the Pleistocene was a variable time period in terms of climatic conditions. This is not reflected in the diatom record which shows this to be a stable freshwater littoral system. This suggests that the type of changes that were occurring did not affect the factors which most influenced the diatom populations at that point e.g. habitat.
2. The transition to the Holocene was arid according to the oxygen isotope data and this is matched by a time of very poor diatom preservation. With improved dating control this may be proved to be a Younger Dryas signal.
3. From c.9200-5100 years BP the oxygen isotopes record stable and moist conditions. This is the most stable phase of diatom preservation being characterised by changes in species dominance rather than shifts in species.
4. 5500-5400 years BP is a distinct negative shift in the $\delta^{18}O$ record and a positive shift in the $\delta^{13}C$ record. This is the first preliminary evidence for catchment disturbance. From 6020-4752 ^{14}C years BP the highest rates of sediment accumulation occur. This is further evidence that this period was one of change.
5. From 5000 years BP to the top of the record diatom preservation is very variable as are the signals from the stable isotope data. From approximately the same time period there is an increase in the disturbance pollen and a negative trend in the $\delta^{18}O$ data which suggests that this is when the influence of humans began in this area.
6. From 4800 years BP the abundance of pine pollen increases which implies a drier climate. This is backed up by a shift to a positive trend in the $\delta^{18}O$ record at c. 3000 years BP. This suggests that the shift to late Holocene dry conditions was gradual.
7. Evidence from Hillbank 2000 highlights the impact of colonial activity in the catchment in terms of catchment disturbance.

Hillbank, New River Lagoon

Basemap: DOS Sheet 15, Edition 5-GSGS (1993), Scale 1:50,000
Projection: Universal Transverse Mercator (Zone 16)

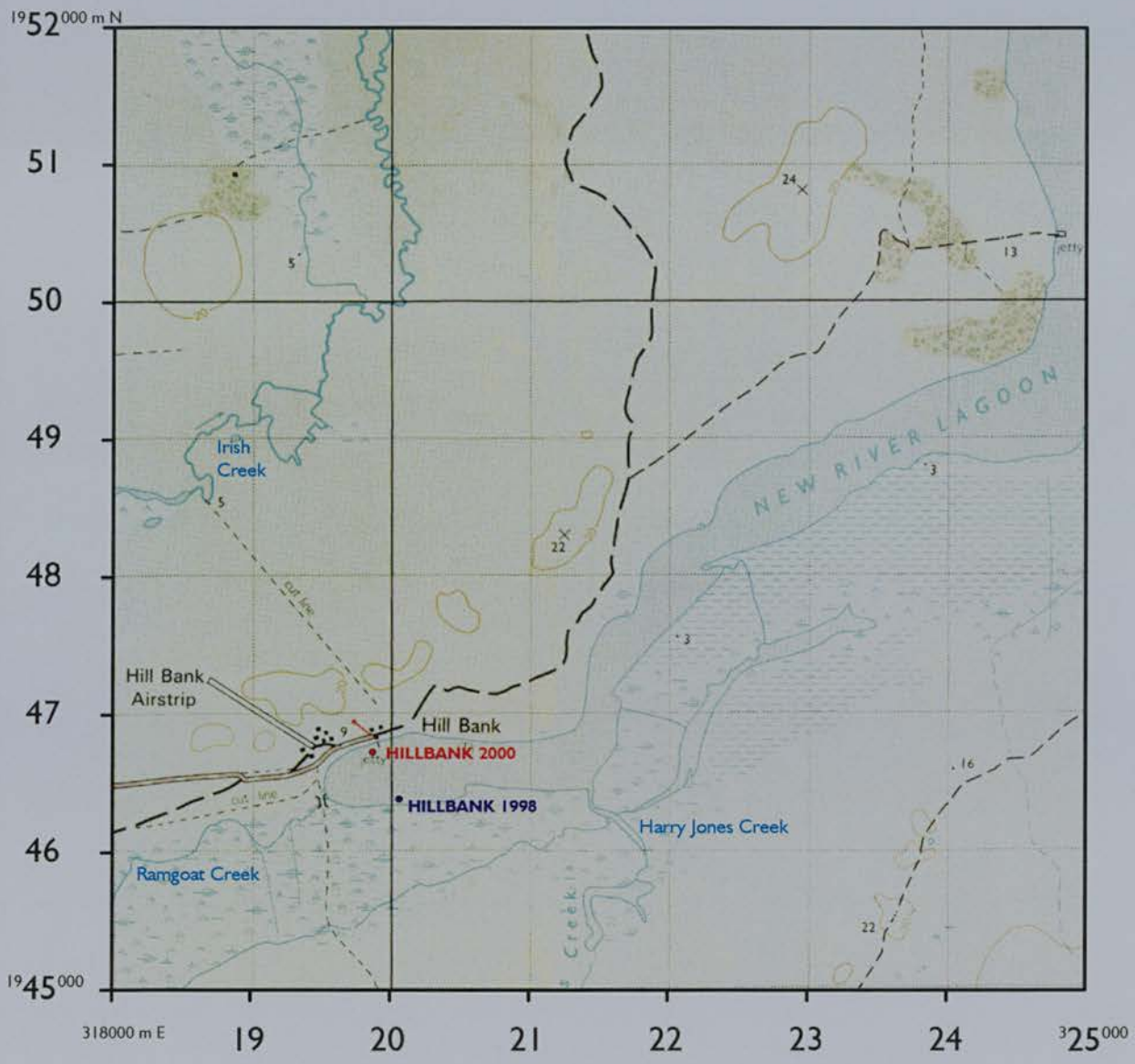


Figure 6.1
Modified from Murray (unpub.)

Figure 6.2 Hillbank, New River Lagoon

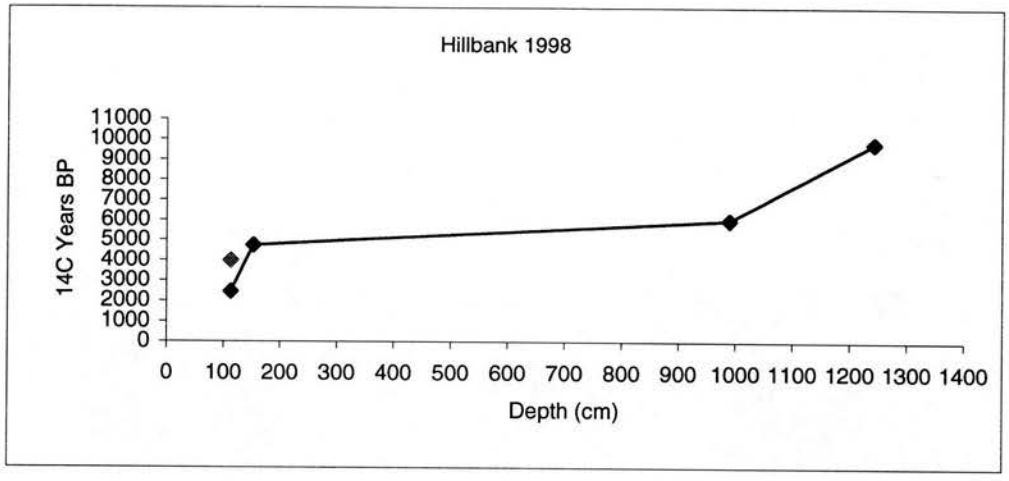
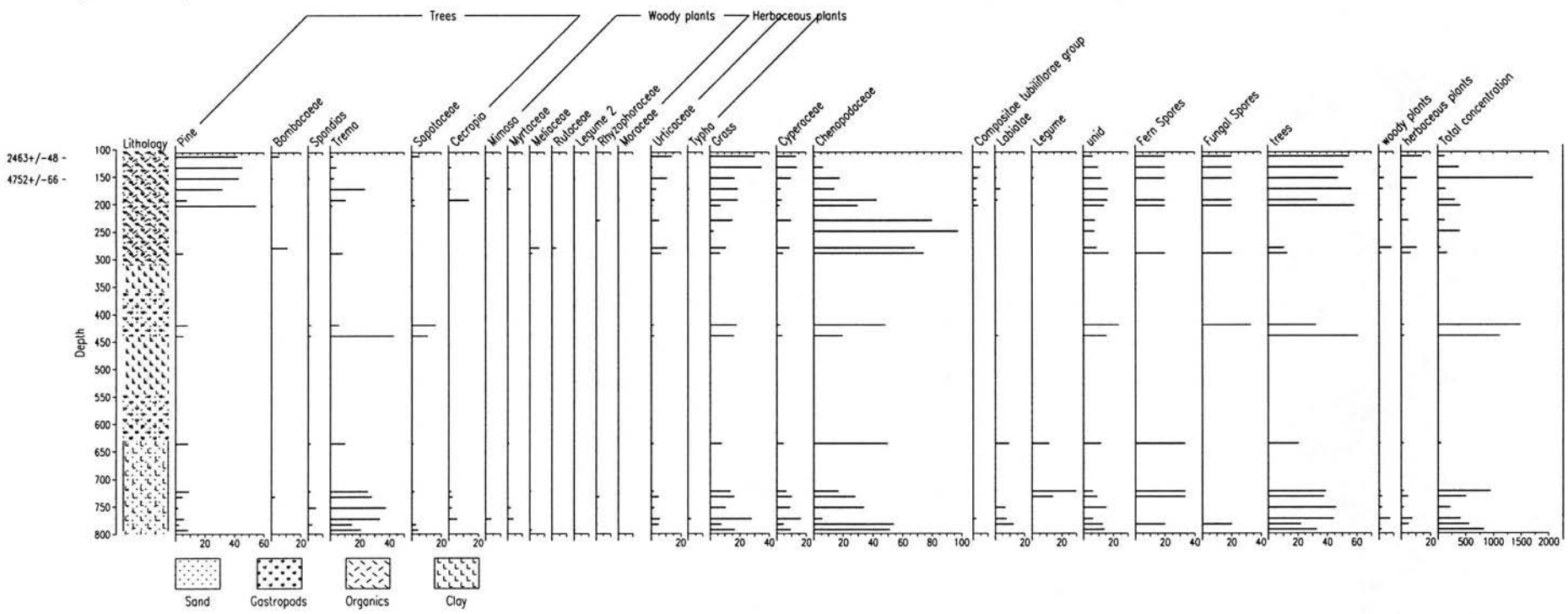
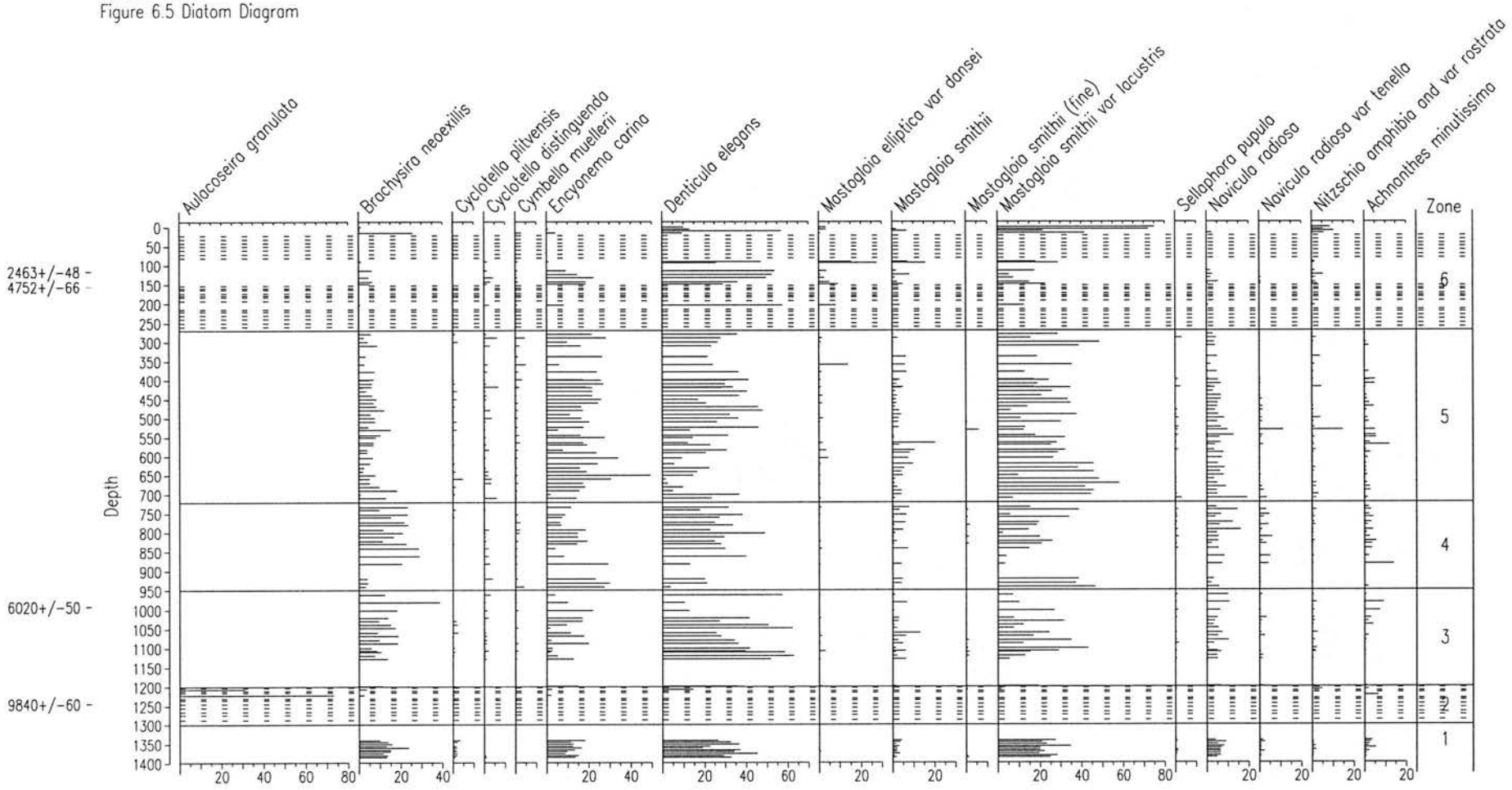


Figure 6.3: Radiocarbon dates for Hillbank 1998. The points joined up by the line are from terrestrial organic matter. The single point is the date from the gastropod. The error ranges can be found in Table 6.1.

Hillbank 1998
Figure 6.4 Pollen Diagram



Hillbank 1998
Figure 6.5 Diatom Diagram



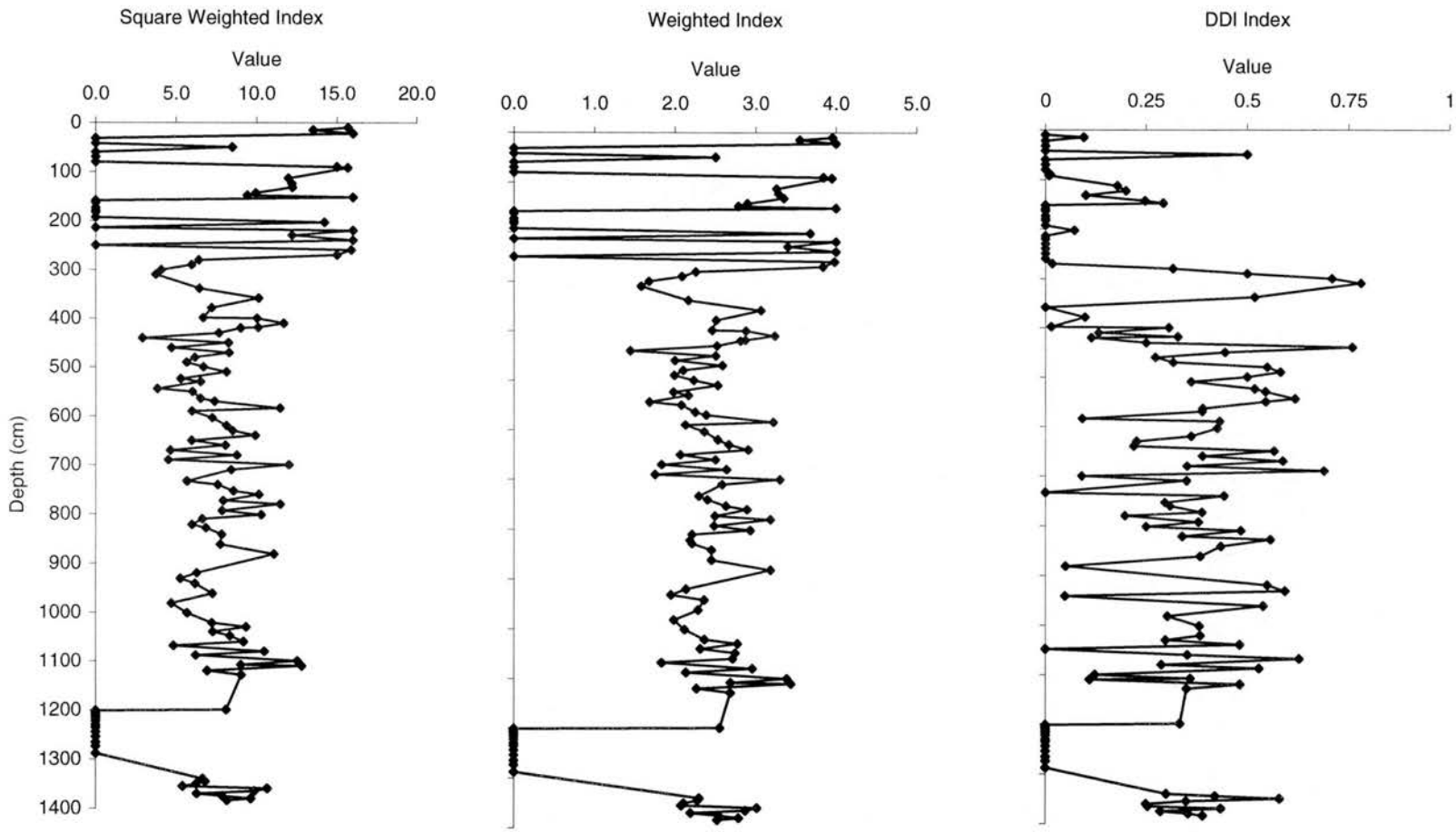


Figure 6.6 Hillbank 1998 A comparison of the three dissolution indices used in this study

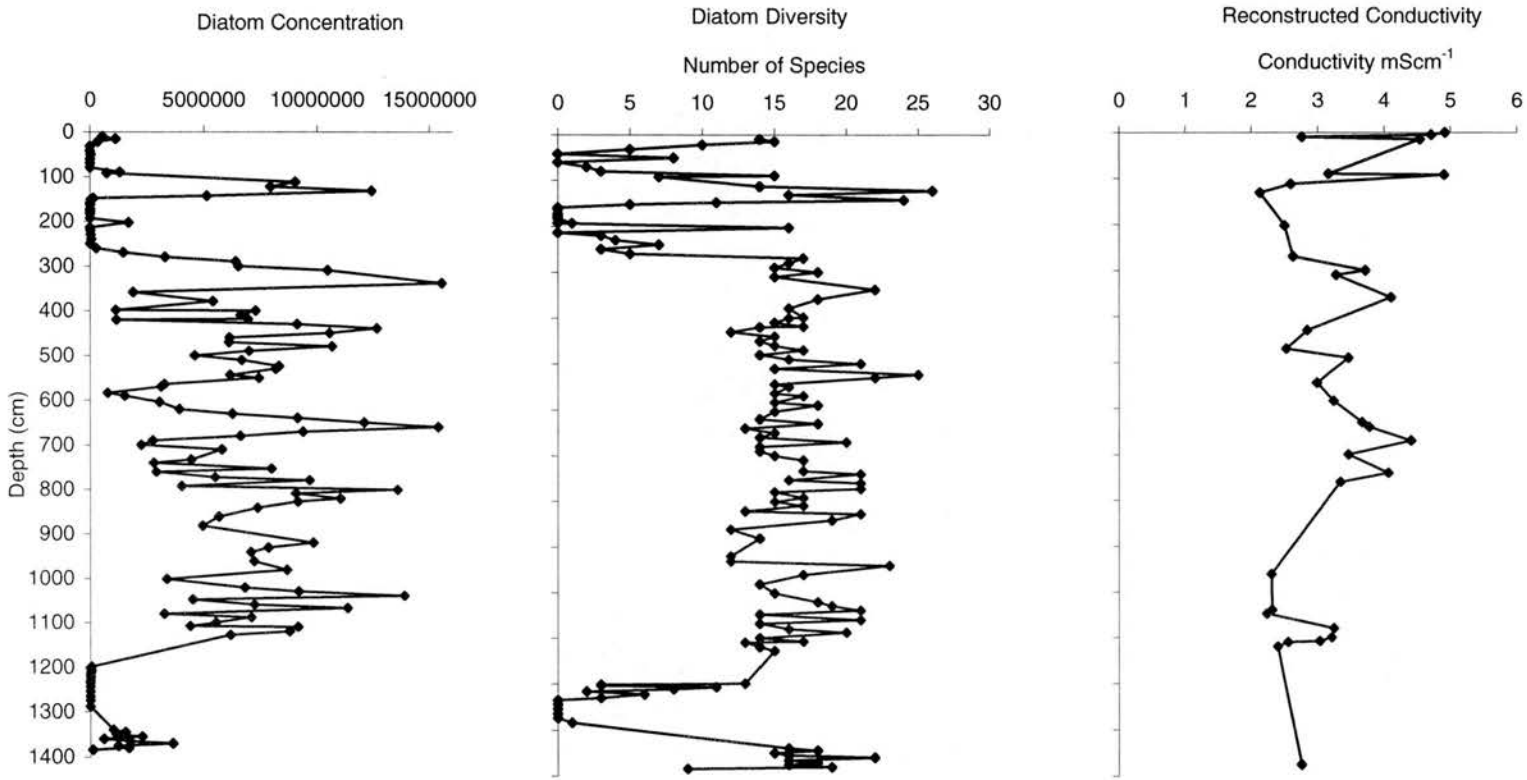
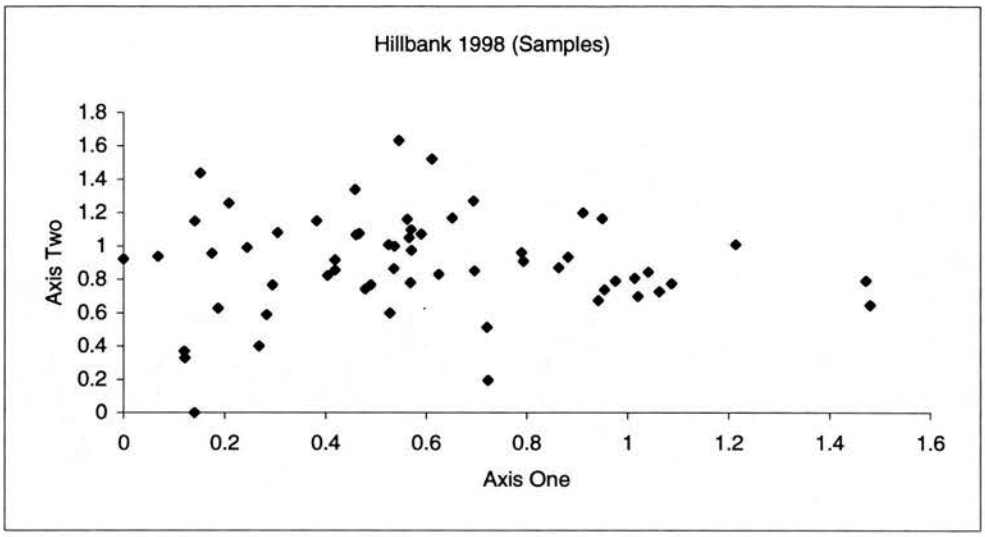


Figure 6.7 Hillbank 1998: diatom concentration, diversity and reconstructed conductivity.



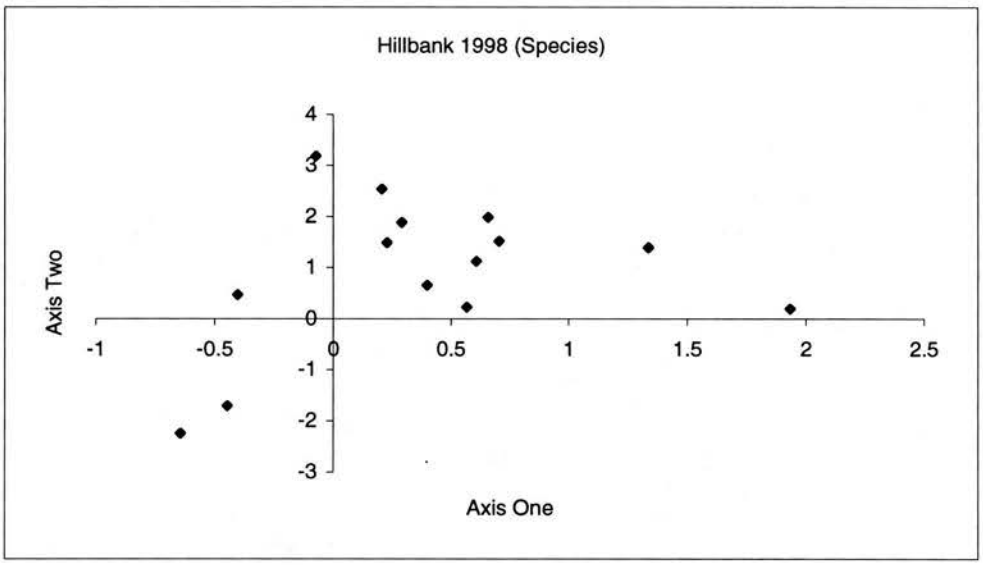
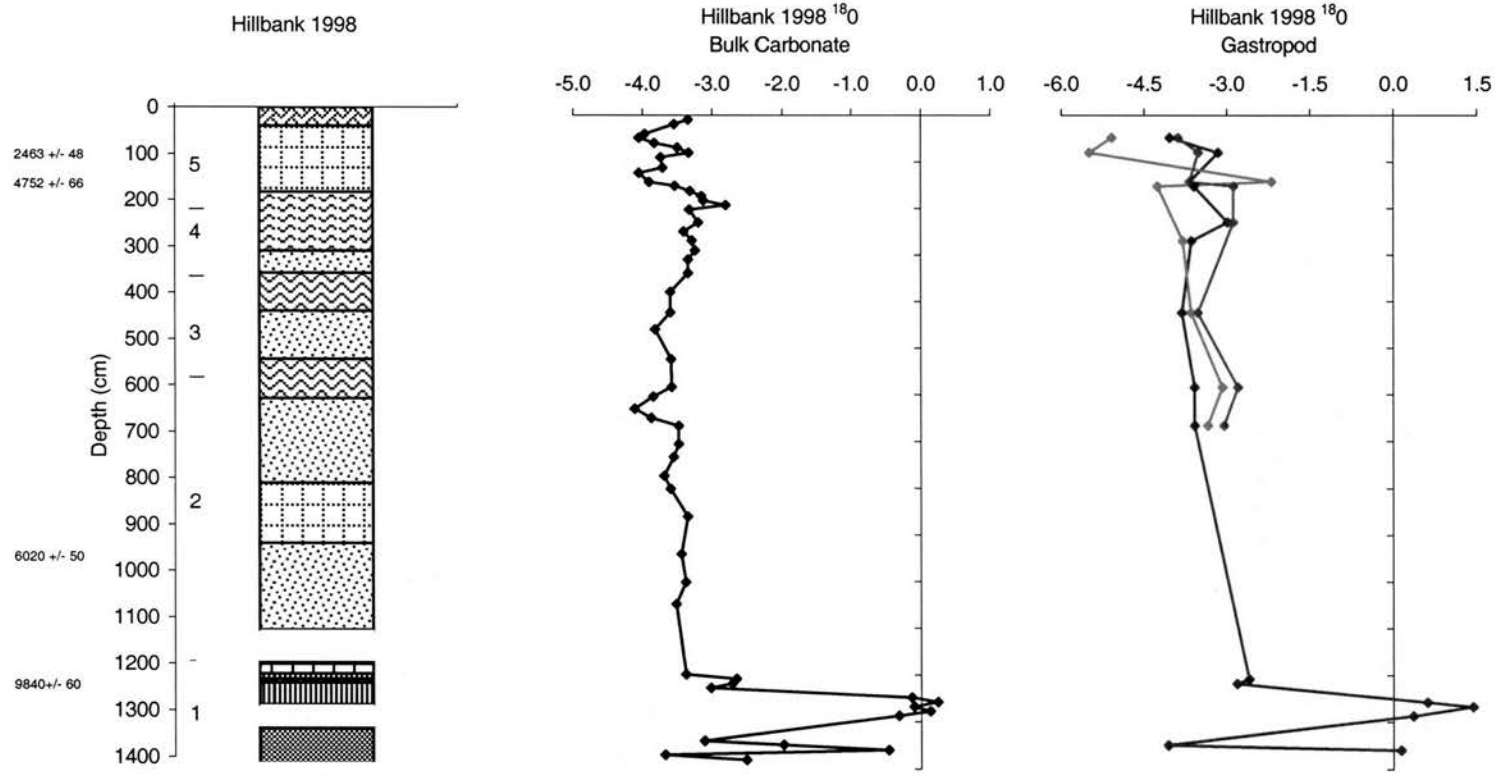


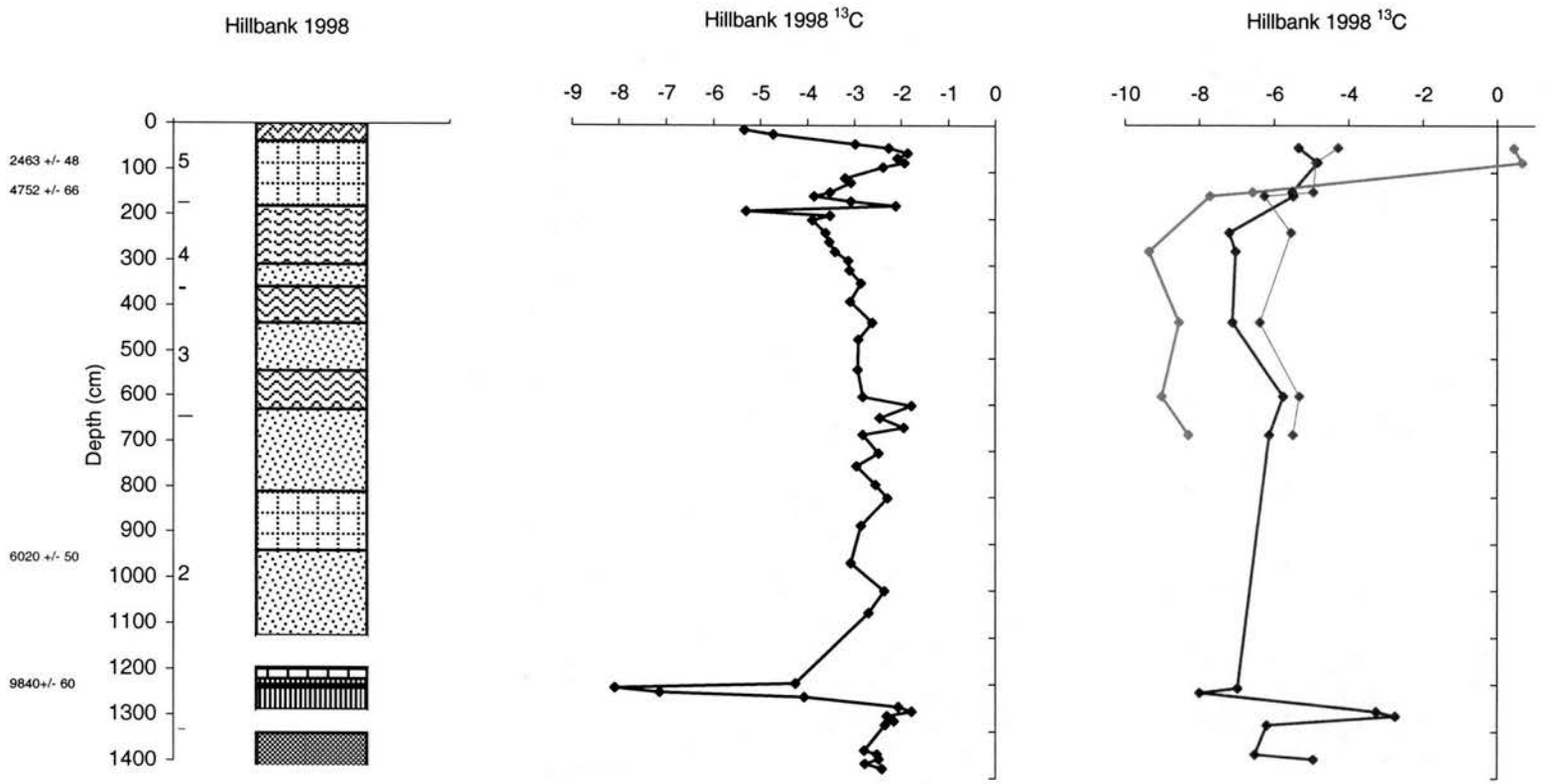
Figure 6.8 Hillbank 1998 Detrended Correspondence Analysis results
The graphs both show scatter, suggesting that the differences between depths are shifts in the dominance of species rather than completely new assemblages.



The gaps indicate where sediment is missing

Blue: Cochliopina sp
Green: Pygophorus sp
Pink: Unidentified sp

Figure 6.9 Hillbank 1998 ^{18}O



Gaps indicate where sediment is missing

Blue: Cochliopina sp
Green: Pygophorus sp
Pink: Unidentified sp

Figure 6.10 Hillbank 1998 ^{13}C Records

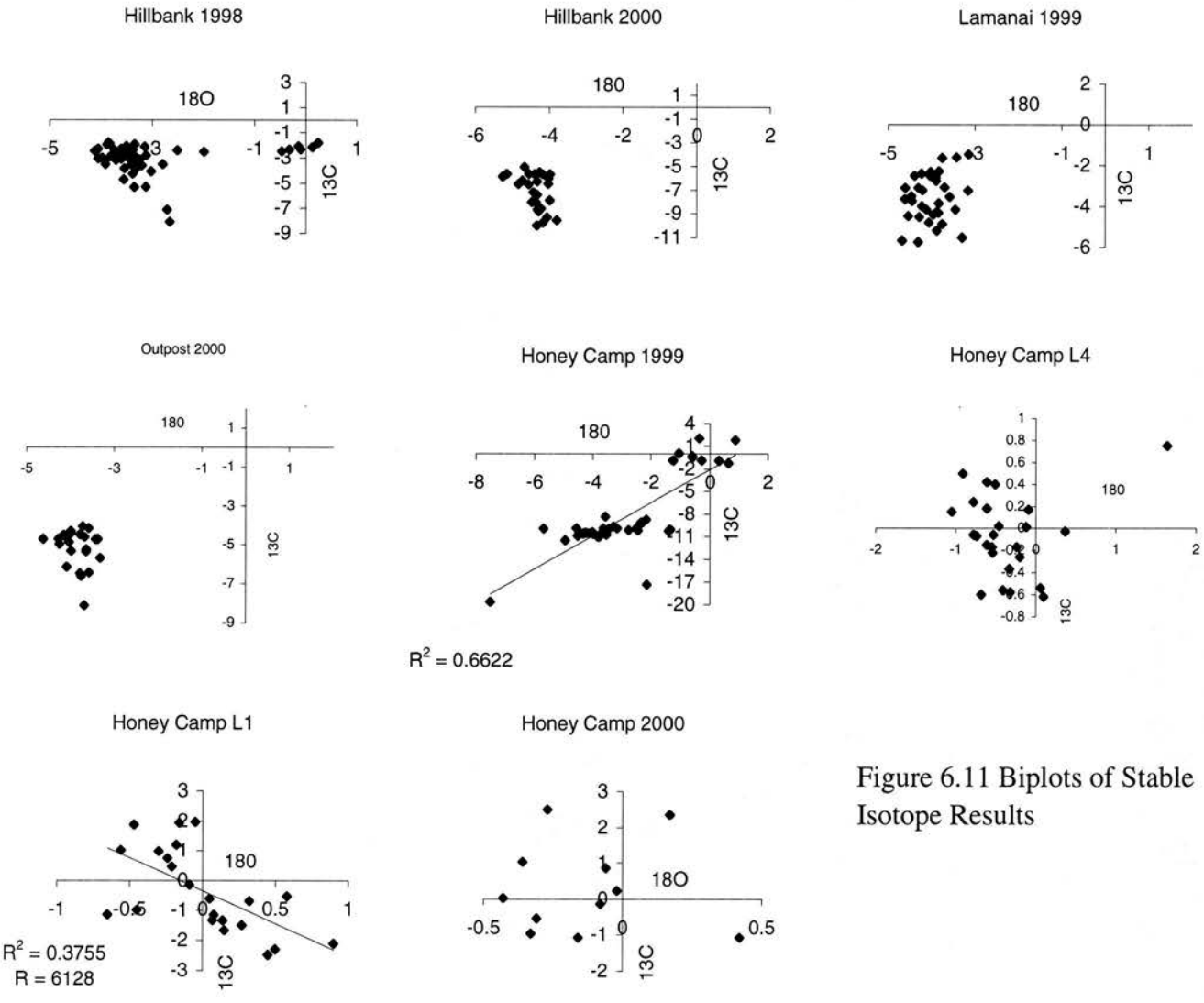


Figure 6.11 Biplots of Stable Isotope Results

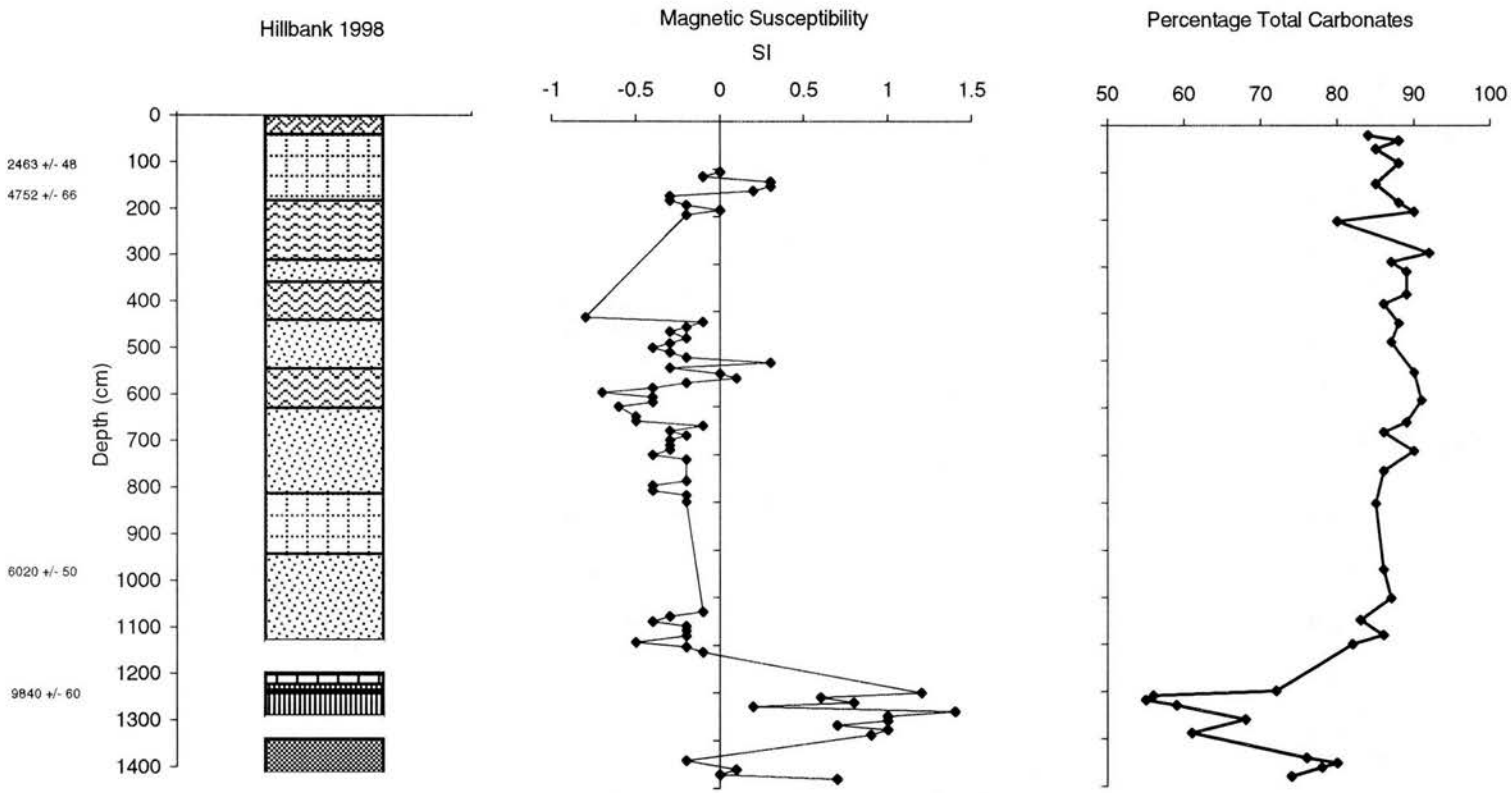


Figure 6.12 Hillbank 1998: Magnetic susceptibility and percentage total carbonate results

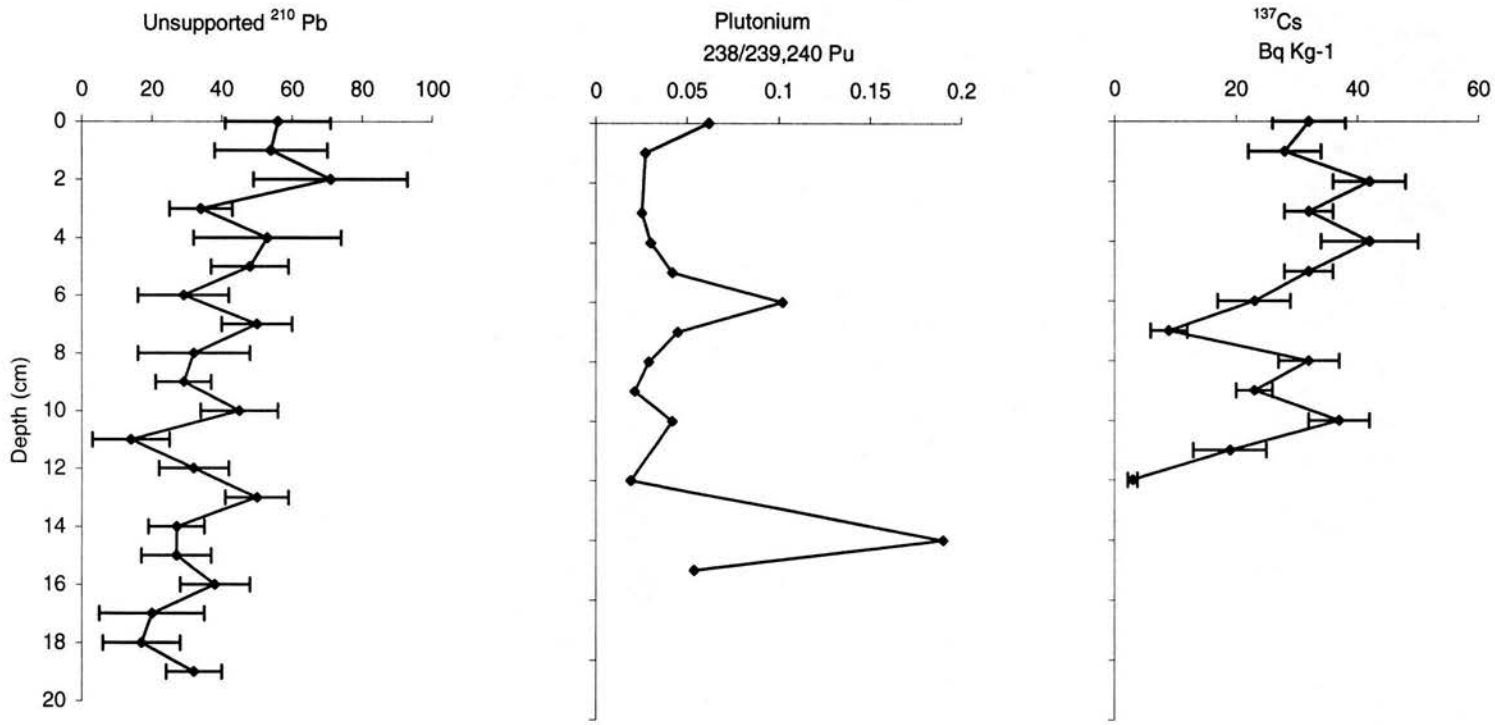


Figure 6.13 Hillbank 2000 ^{210} Pb Results

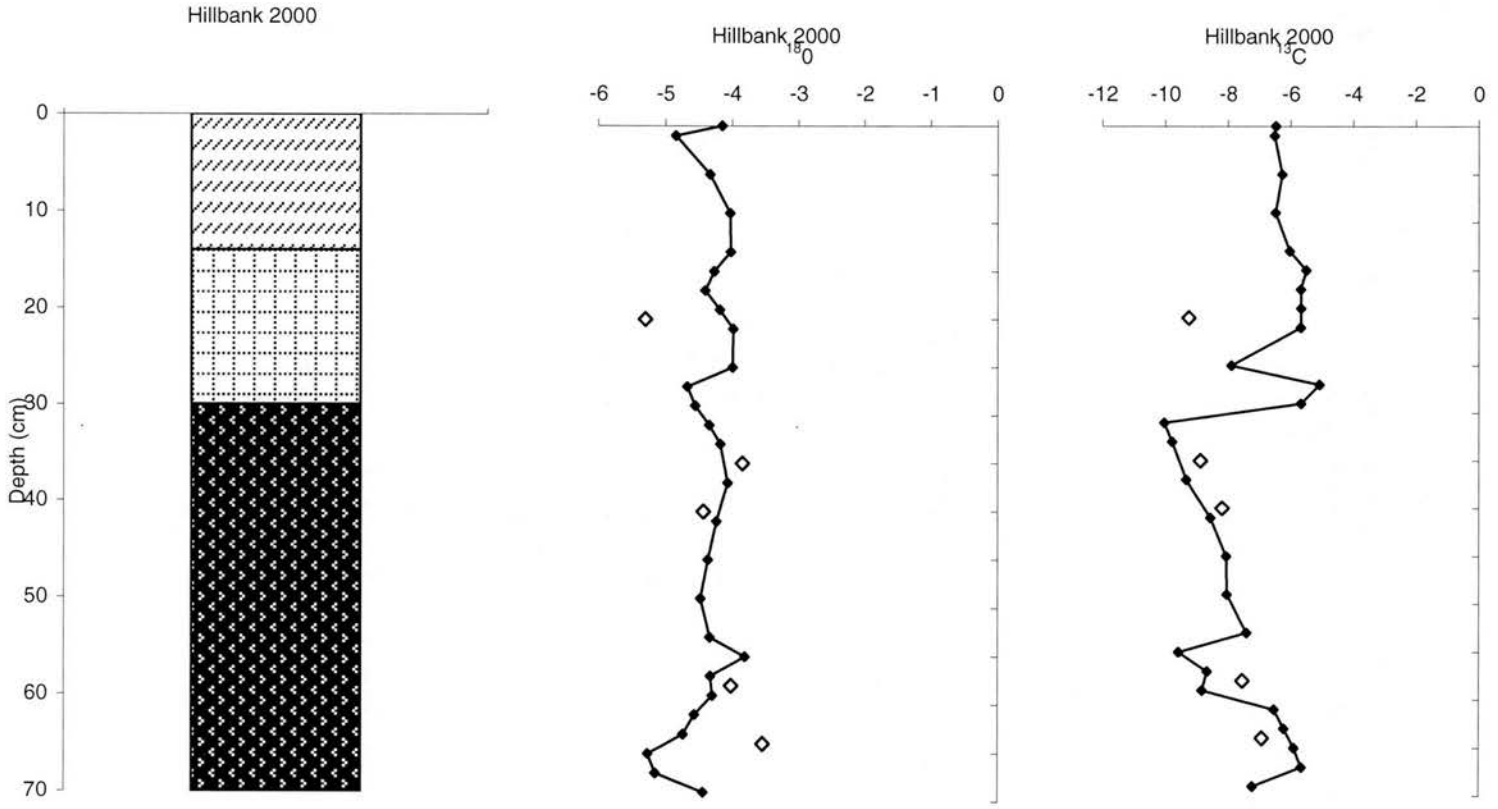


Figure 6.14 Hillbank 2000 ^{18}O and ^{13}C Records
Open Diamonds = Cochliopina sp.

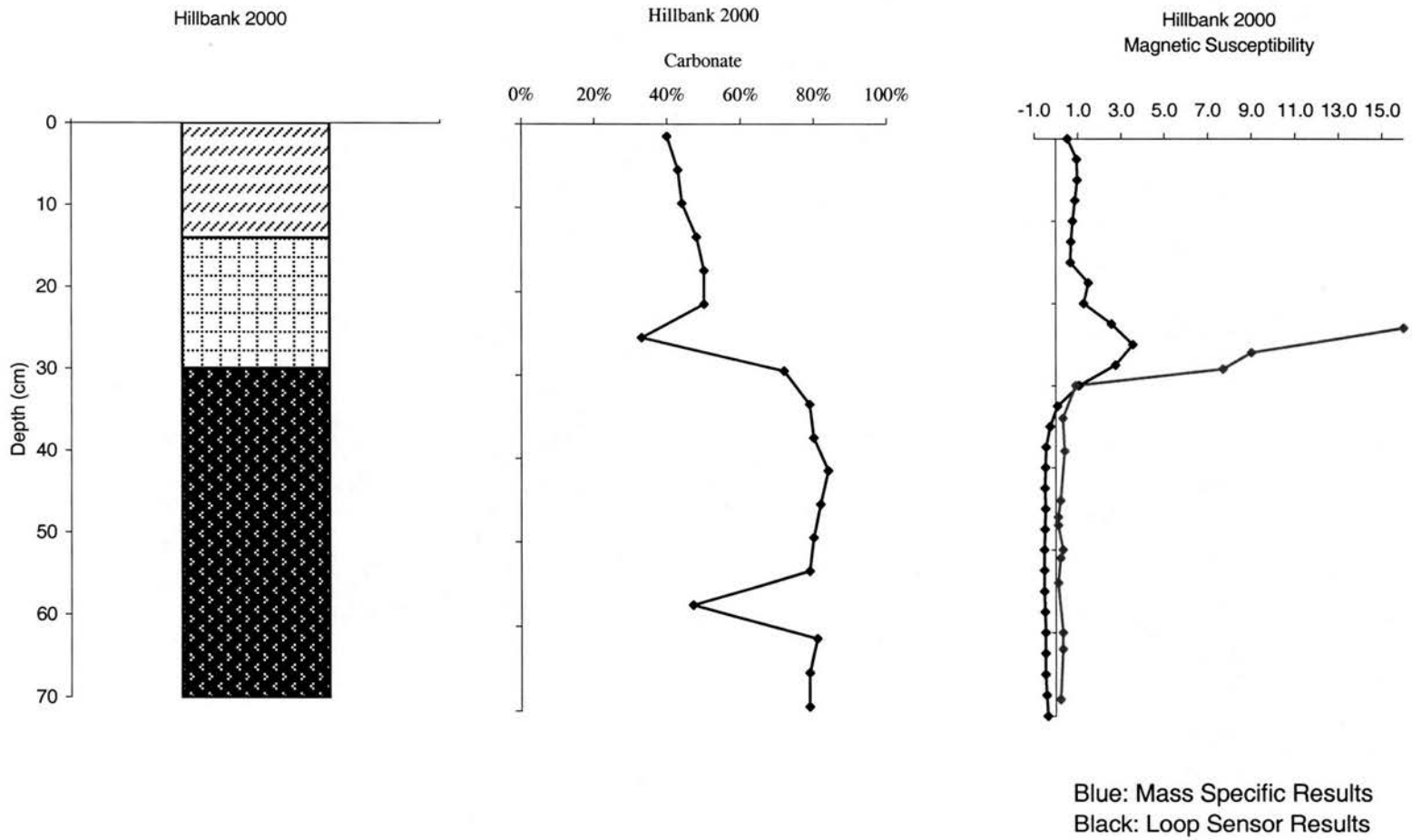
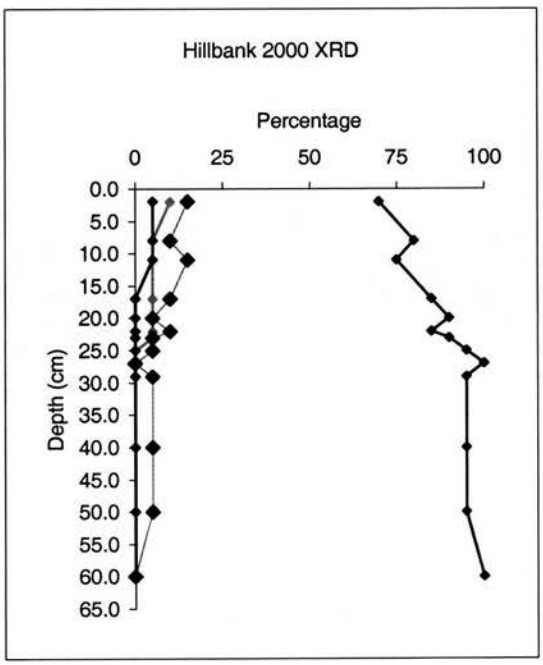


Figure 6.15 Hillbank 2000 Carbonate and Magnetic Susceptibility results

Figure 6.16



Blue: Calcite
Pink: Quartz
Green: Pyrite
Black: Dolomite

Chapter Seven: The Results from Lamanai, New River Lagoon

7.1 Lamanai 1999

This chapter presents and discusses the results from Lamanai, New River Lagoon. The location of the first core (Lamanai 1999) is shown in Figures 7.1- 7.2 and the stratigraphy of this core is detailed in appendix 6. Two cores were taken from this area in a similar manner to Hillbank which is located due south of this site.

There are four radiocarbon dates for the Lamanai 1999 sequence (which are also shown in Figure 7.2):

Table 7.1

Lab Code	Depth (cm)	Material	^{14}C Years BP	$\delta^{13}C_{PDB}‰$ +/- 0.1	Calibrated Age	2 Sigma range
CAMS-77195	312	OM	3440+/-40	-28.6	1741 BC	1880-1636 BC
AA-35786	259	OM	3070 +/-50	-27.1	1374, 1338, 1319 BC	1433-1132 BC
AA-35787	38.5	OM	810+/- 40	-32.4	AD 1224, 1231, 1239	AD 1161-1283
CAMS-77196	38.5	G	2470+/-40	-6.9	/	/

The dates were calibrated according to Stuiver *et al.* (1998).

The hard water lake error from the paired date at 38.5cm is 1660 ^{14}C years BP. This, in a similar manner to Hillbank, is in keeping with published estimates (see section 4.6.2). This evidence supports the idea that a general correction factor can be applied to lakes in this region (Hodell *et al.*, 1991; Leyden *et al.*, 1993; Hodell *et al.*, 1995; Curtis *et al.,* 1996 and Leyden *et al.*, 1998).

7.2 The Diatom Results from Lamanai 1999:

All the diatom species mentioned in this chapter can be found in appendix 2. The diatom diagram (Figure 7.3) has been split into 7 zones based on the major shifts in the flora:

Zone 1 - 318-221cm:

The base of the sequence is mainly barren of diatoms except for alternating zones which are dominated by two different assemblages of diatoms. The first assemblage comprises *Denticula tenuis*, *Nitzschia amphibia* var. *rostrata*, *Mastogloia smithii* var. *lacustris* and *Mastogloia smithii* var. *lacustris* (fine). This latter species was discussed in greater detail in Chapter 5 and it represents sedimentary rather than epiphytic environments. In general terms, this assemblage of species suggests a littoral lake environment. *Denticula tenuis* is thought to be indicative of medium conductivities and is found in littoral environments (Krammer and Lange-Bertalot, 1988). *Denticula tenuis* does not occur in conjunction with the species in this zone in the modern environment and is only found in very low levels in three of the sites sampled in Belize: Booth River (plankton); Progresso Lagoon (epiphyte) and Crooked Tree Lagoon (plankton) (Figure 4.1). These sites all fall into different water chemistry groups. Booth River is a calcium-sulphate system; Progresso Lagoon is sodium-chloride dominated and Crooked Tree Lagoon is calcium-sulphate/total carbonate. This implies that the species must be quite cosmopolitan and therefore easily out-competed by species that are experiencing their optimum conditions.

Denticula elegans, *Mastogloia smithii* var. *lacustris*, *Brachysira neoexilis* and *Nitzschia amphibia* var. *rostrata* dominate the second assemblage of this zone. This is a slightly different assemblage and because *Denticula elegans* is thought to be a marsh species this suggests that the times when this species is prevalent is during low water level conditions. *Nitzschia amphibia* var. *rostrata* is not common in the sites sampled in Belize. The site which has the closest population to this assemblage is Hillbank (3) sediment (Figure 5.2). This is a shallow water site that is surrounded by algae and vegetation which supports the interpretation of *Denticula elegans*.

Zone 2 - 221-181.5cm:

This zone is the first prolonged period of diatom preservation and it is dominated by *Denticula elegans*, *Nitzschia amphibia* var. *rostrata*, *Mastogloia smithii* var. *lacustris*, *Mastogloia smithii*, *Mastogloia smithii* var. *lacustris* (fine), *Brachysira neoexilis* and *Cyclotella distinguenda*. The fact that diatom preservation occurs over

an extended period suggests that the system is more stable during this phase. *Cyclotella distinguenda* was not found in any of the modern sites and *Mastogloia smithii* is very rare. This implies that the environmental conditions which this zone represents are different to those that are found in the modern areas sampled. Reed (1998a) found *Cyclotella distinguenda* in her samples from Spain, in oligosaline, littoral environments. She classified it as facultatively planktonic. The ecological differences between *Mastogloia smithii* and its variety are not clear, but the contrast in their distribution suggest that they do respond to different variables. The highest percentage of population of *M. smithii* is in Honey Camp Lagoon (algae) sample at 4% (Figure 4.2). This is also the site where the highest percentage of *M. smithii* var. *lacustris* occurs at 48%. This site had (in relation to the other freshwater sites sampled) high conductivity and sodium-chloride levels. This suggests that, in terms of measured variables their optimum conditions are the same, but there must be a reason why *M. smithii* var. *lacustris* is able to so effectively out-compete the nominate form.

Zone 3 - 181.5-172.5cm:
This zone is barren of diatoms.

Zone 4 - 172.5-74cm:
This zone is an extended period of diatom preservation where new species are introduced into the record. It is dominated by *Nitzschia amphibia* var. *rostrata*, *Achnanthes exigua* var. *exigua*, *Achnanthes minutissima*, *Brachysira neoexilis*, *Cyclotella distinguenda*, *Encyonema carina*, *Gomphonema gracile*, *Mastogloia smithii* var. *lacustris*, *Mastogloia smithii* var. *lacustris* (fine) and *Nitzschia amphibia*. These species are again found in littoral environments (Krammer and Lange-Bertalot, 1986; 1988; 1991a; 1991b and Reed 1998a). The diversity of species is high in this zone which suggests that the environmental conditions at this time were amenable to more diatom species. Although *Cyclotella distinguenda* is not found in any of the modern samples, the rest of the species dominate the modern site Hillbank (1) sediment. This site is on the opposite shore from Hillbank (3) i.e. the marsh side (Figure 5.2). Sediment samples are an average of all the different inputs into the

system and therefore represent all the environments in the area. This suggests that the environment of this zone, like Hillbank 1, was a marsh edge which would have had a great diversity of habitats in which different diatom species could flourish.

Zone 5 - 74-40cm:

The number of diatom species drops in this zone and there is an abrupt transition to a new diatom assemblage. *Denticula elegans* dominates this sequence with *Cyclotella plitvicensis*. Other species that are present include *Brachysira neoexilis*, *Mastogloia smithii*, *Mastogloia smithii* var. *lacustris* (fine), *Nitzschia amphibia* var. *rostrata* and *Sellaphora pupula*. This is a clear shift in the flora and therefore represents a time of environmental change. *Cyclotella plitvicensis* is not found in the modern sites sampled and *Mastogloia smithii* and *Navicula pupula* are also not common species. This zone therefore represents an environment that has not been sampled in modern day Belize. The modern site which contains the highest numbers of *Denticula elegans* is Progresso Lagoon (epiphyte). This lagoon has a conductivity of 7.25mS cm^{-1} and is dominated by sodium-chloride. *Nitzschia amphibia* var. *rostrata* and *Mastogloia smithii* var. *lacustris* (fine) are littoral mud species and *Sellaphora pupula* is widespread in its distribution. The ecology of *Cyclotella plitivicensis* is unknown. These species suggest that this was a time of shallow waters, high conductivity and very little large vegetation at this site (Krammer and Lange-Bertalot, 1991a). This cannot be substantiated without ecological knowledge of *C. plitivicensis*.

Zone 6 - 40-9cm:

This zone is barren of diatoms.

Zone 7 - 9-0cm:

Within this very small zone the diatom population moves from one which is dominated by *Denticula elegans* and *Brachysira neoexilis* to one which has a much more diverse flora including the varieties of *Brachysira neoexilis*, *Achnanthes minutissima*, *Mastogloia smithii* var. *lacustris*, *Nitzschia amphibia* var. *rostrata*, *Navicula radiosa* and *Navicula radiosa* var. *tenella*. This is not an assemblage that

has been present in the past. The section dominated by *Denticula elegans* and *Brachysira neoexilis* is similar to Hillbank (2b) sediment (Figure 5.2). This was a site which was away from the large reeds of the marshland and in slightly deeper water. This does not support the interpretation that *Denticula elegans* is a marsh species. The second assemblage is not one which is found in the modern environment suggesting that in a similar manner to Hillbank, the top of the core is not the present day. This is not surprising because the top sediments in Lamanai were extremely unconsolidated.

The graph of reconstructed conductivity (Figure 7.4) contains only the depths that have 70% or more of the species in common with the modern data set. The division which is immediately obvious is between the diatom zones 1 and 2 and zones 4 to 7. The first two zones have an average reconstructed conductivity of 3.6 mS cm^{-1} and the top zones have an average of 1.94 mS cm^{-1}. This is a significant difference and its suggests that zone 3, which is barren of diatoms, is a distinct event which separates two different states in the lagoon's history. The conductivity reconstruction is based upon the species that are present at each depth. The value produced is therefore dependent on those species. The average value for the top zones (which represents the period from c. 2152 years BP onwards) has a reconstructed value that is closer to the modern measured conductivity values for Lamanai (0.91-1.07 mS cm^{-1}) than the previous zones. From this information it is likely that the reconstructions are probably in the right range and that the lagoon was quite different to the past. This provides more confidence in the use of the Spanish training set. The species diversity in zones 4-7 is higher than zones 1-2 with an average of 22 species as compared to 13 species per depth (Figure 7.4). This suggests that the environmental conditions in the top part of the record were more amenable to a greater number of species. The higher conductivity in the lower half of the sequence may be part of the reason why diatoms are fluctuating between presence and absence. Unlike Hillbank 1998 species diversity does not appear to be so clearly linked to diatom concentration. This suggests that the environmental changes that are influencing diatom numbers are not severe enough to result in an environment in which only a limited number of species can survive.

Figure 7.5 shows the dissolution indices. The DDI clearly shows the division between zones 1 –2 and 4-7. The lower zones have either no preserved diatoms or very badly preserved specimens. In a similar manner to the results from Hillbank this means that information has been lost. The upper zones still exhibit very variable preservation but higher proportions of well-preserved valves are found. The transition to zone 4 coincides with the period of highest diatom concentration in the entire sequence (Figure 7.4). A clearer picture of preservation changes in this sequence is gained from the weighted and square-weighted indices. In a similar manner to the DDI they show the division between the top and bottom half of the record. Zones 1 and 2 are characterised by three clear cycles where preservation is poor but is punctuated by short periods of improved preservation. The upper half of the record is much more variable but on the whole the diatoms are better preserved. The use of preservation indices has enabled a greater appreciation of the variable preservation levels through the sequence even through zones of seemingly stable conditions.

In order to gain a greater understanding of the relationships between depths a DCA analysis was undertaken on the core data. This methodology is explained in more detail in Chapter 4. These results are shown in Figure 7.6. The eigenvalues for the axes are not high with axis one being 0.5258 and axis two being 0.1606, but the axes are fairly long (in comparison with the Hillbank axes shown in Figure 6.8) which suggests that the axes represent some form of environmental gradient. This is directly related to the species that are found in the depths. The species form two groups. These are not tightly clustered and thus the only conclusion that can be made at this stage is that the species in 'group' one are associated with each other because they are not associated with the species found in 'group' two.

'Group' one: *Achnanthes exigua*, *Brachysira neoexilis*, *Cocconeis placentula* var. *placentula*, *C. placentula* var. *incisa*, *Cyclotella distinguenda*, *Denticula elegans*, *Encyonema carina*, *Gomphonema gracile*, *Navicula radiosa* (diamonds).

'Group' two: *Denticula tenuis*, *Mastogloia smithii*, *M. smithii* var. *lacustris* (open squares).

The main point that these groups highlight is the division between *Denticula elegans* and *M. smithii* var. *lacustris* which adds weight to the argument that the shifts between these species, that are seen in the record, do represent times of environmental change. The depths do not appear to form any form of coherent grouping apart from those shown as open circles. These are all depths where *Denticula elegans* is extremely dominant as compared to *Mastogloia smithii* var. *lacustris*.

To summarise, the diatom record from Lamanai can be split into three periods. From the base of the record to 181.5cm diatom zones 1 and 2 are found. These zones are characterised by low species diversity, poor preservation and the diatom species reflect 'high' salinities (3.49-3.7 mS cm^{-1}). The environment is one of a littoral lake edge community that is fringed with vegetation. From 181.5-172.5cm there are no diatoms preserved. This represents a significant event because it forms the transition zone between two different lagoon states. From 172.5cm to the top of the record diatom zones 4 to 7 are found. These are characterised by high species diversity, variable preservation (which does reach quite high levels) and low reconstructed salinity (1.55-2.6 mS cm^{-1}). The key change in the environment, which the diatoms show, is an increase in the amount of vegetation through time with a more marsh-like ecosystem predominating.

7.3 The Stable Isotope Results:

Both oxygen and carbon isotopes were measured from this core from bulk carbonate samples every 5-10cm (Figure 7.7). The amount of variability throughout the whole record is low with a $\delta^{18}O$ range of 2.2‰.

The $\delta^{18}O$ record is characterised by a constant series of small scale shifts which are forceful enough to stop the system from maintaining a steady state. At particular

points in the record the shifts are larger than 'normal'. The points that exhibit more than +/- 1 SD of the average change are 39, 42, 174 and 178cm. The most significant of these episodes is at the top of the sequence where $\delta^{18}O$ values reach -5.3‰ (42cm). This is the most negative excursion in the whole sequence.

The $\delta^{13}C$ record (Figure 7.7) shows greater shifts than the $\delta^{18}O$ record suggesting there have been significant modifications to the carbon sources in the system. The record can be split into three zones which match the $\delta^{18}O$ record (Figure 7.7):

1. 307-178cm
2. 178-42cm
3. 42-0cm

Discussing each zone in turn:

Zone 1: The scale of the shifts in this zone are similar to those at the top of the record. The general values are however more negative.

Zone 2: This zone can be split into three phases of prolonged negative departures in the $\delta^{13}C$ values. After each negative excursion the $\delta^{13}C$ values return to approximately the same value between -3.9‰ and -4.5‰.

Zone 3: This zone is characterised by small and short-lived shifts in $\delta^{13}C$.

In general terms it is apparent that at the beginning and end of the record, the $\delta^{18}O$ and the $\delta^{13}C$ records are responding in a comparable manner with the level of variability between layers being of a similar magnitude. The beginning and end of the second phase in the carbon record is bracketed by the two largest shifts in the $\delta^{18}O$ record. This suggests that these two shifts in the $\delta^{18}O$ record are very significant and that zone 2 in the $\delta^{13}C$ record does indeed represent a time when the system operated in a different manner.

7.4 The Results From Further Proxies:

Lamanai 1999 has also been analysed for percentage calcium carbonate, Loss On Ignition, available phosphorus and C:N ratios (see Chapter 4).

The percentage of calcium carbonate in the core is uniformly high but there are trends which can be recognised (Figure 7.8). The record can be effectively split into three zones:

Zone 1: Base – 171cm: This zone shows a gradual trend increasing levels of calcium carbonate. Average value = 74%

Zone 2: 171-42cm: Within this zone the shifts are much more long-lived and the lowest value in the sequence is found at 143cm (60%). Average value = 74%

Zone 3: 42-0cm: Levels in this zone are very steady and average the highest in the sequence at 80%.

Trends are difficult to identify in the Loss On Ignition record (Figure 7.8). The values in this record are low ranging from 3.5-11.3%. The key interval that stands out is from 174-113cm which contains peaks at 134 and 144cm. This is the only period of extended change in the system. LOI is a measure of the amount of organic matter in the system and this peak is matched by a drop in the percentage of calcium carbonate in the system.

The available phosphorus record can be split into four zones (Figure 7.9):

Zone 1: Base – 171cm: This zone is characterised by short-lived but large excursions in the amount of available phosphorus. An extended excursion occurs between 234-210cm. After this point the excursions are smaller in magnitude.

Zone 2: 171-90cm: This period begins with very stable values which rapidly reach a peak at 140cm. The changes in the values after this point are short-lived.

Zone 3: 90-38cm: The values are very stable through this zone.

Zone 4: 38-0cm: This zone records a rapid drop in values reaching zero at 18cm. By the top of the sequence the values exhibited in zone 3 have been restored.

The fact that this record can be categorised into the same zones as the isotope records suggests that these really are periods when the system was undergoing radical changes. This record does not however provide the definitive answer to phosphorus

patterns in the area. This is because it is the bulk movement of soils that is the key mechanism by which phosphorus reaches lakes and therefore total phosphorus would provide a clearer idea of changing phosphorus levels in the system (Brenner, 1983).

C:N ratios were measured on this core (Figure 7.9). The ratios suggest that the key input into the system is terrestrial organic matter throughout the entire sequence because the values are all greater than 20 apart from at the very top of the sequence (Kaushal and Binford, 1999). This record can be split into four phases:

Zone 1:Base-269 cm: This zone is characterised by the two large positive excursions at 294cm and 274cm. These suggest that the system was experiencing disturbance during this time frame.

Zone 2: 269-180cm: This zone is characterised by very stable levels of C:N ratios apart from an excursion at 205cm. This coincides with the initial prolonged excursion in the $\delta^{13}C$ record.

Zone 3: 180-45cm: This zone is also characterised by stable values but these are all less positive than in the previous phase. There are two large positive excursions at 175 and 90cm.

Zone 4: 45-0cm: This follows a negative trend to the top of the record. From 8cm the least positive values for the whole sequence are found.

The X-Ray Diffraction record is very stable showing one period of change in the system (Figure 7.10). At 177cm there is a rise in the amount of aragonite in the system which is during the zone 3 in the diatom record. This change in the sediment confirms the significance of this key transition zone. Aragonite is the stable form of calcite in hypersaline conditions which is preliminary evidence that this is an arid phase. An alternative explanation is that this is a period of time where there is a high number of gastropods in the sediment.

7.5 Preliminary Analysis:

Clear zones of change have been identified in the Lamanai 1999 core. The record which shows the most prolonged periods of change is the $\delta^{13}C$ sequence and more

specifically zone 2 within this. In a similar manner to Hillbank, the Lamanai 1999 core was taken from the edge of the lagoon and is therefore most likely to be influenced by changes to the adjacent catchment. The changes in zone 2 are cyclical in their nature which suggests that these might represent periods of increased and decreased activity in the catchment. The $\delta^{13}C$ record has three distinct positive excursions in zone 2. These are estimated to run from:

1. 178-143cm: c.2200-1900 years BP
2. 143-102cm: c.1900-1400 years BP
3. 102-42cm: c.1400-830 years BP

The three events in zone 2 are different in their nature. The first rose to a peak and then returned to previous values, the second has two peaks and the third is a prolonged, but less severe, excursion. As described in Chapter 4 the $\delta^{13}C$ signature of carbonates reflects the $\delta^{13}C$ ratio of lakewater DIC which is controlled by several factors including lake primary productivity, $\delta^{13}C$ of atmospheric CO_2, methanogenesis and the $\delta^{13}C$ of dissolved bicarbonate from the watershed. This latter factor can be affected by the relative abundance of C3 and the isotopically heavier C4 plants in the catchment since these influence the $\delta^{13}C$ of soil CO_2. This equates to a shift from a forested to a tropical grassland catchment. The Lamanai 1999 core was taken from the edge of the lagoon and is therefore likely to be highly influenced by changes to the catchment. The shifts that are seen in the carbon record in zone 2 are positive. One causal mechanism behind these changes may be deforestation events because this would result in a change in the isotopic signature of the incoming material in to the lagoon (i.e. a shift from C3 to C4 plants).

The peaks of these events occurred at 174cm (c.2180 years BP/ 196 BC), 139cm (c.1820 years BP/ AD227), 112cm (c.1540 years BP/ AD 541), 82-46cm (c.1240-870 years BP/ AD 782-1192). In Chapter 3 the construction history of Lamanai was explained. In short, two main phases were defined: the Preclassic and the Classic (1500 BC-AD 600) as the time of monument building and the late Classic and Postclassic (AD 800-1200) as the time of monument modification. It is therefore apparent that the first three peaks in the $\delta^{13}C$ record coincide with the period of

highest activity in the catchment. The magnetic susceptibility record shown in Figure 7.11 shows three main periods of catchment disturbance. It is the second peak that coincides with the AD 227 event and implies that this had the most impact on the catchment. The peak from 82-46cm is much more subdued and is therefore matches the lowered activity in the catchment during the modification phase.

The building of temples would have resulted in a removal of trees from the area which was to be built upon. This would have been compounded by the need to make the lime plaster which covered every temple. An enormous number of trees would have had to be cut down to heat the kilns. Experiments are being undertaken at the moment to determine how much wood had to be burnt to make the amount of plaster that was used at this site (E.Graham pers.com, 2001). In more specific terms monument N10-43 was completed by 100 BC; P9-2 and P8-12 were completed by AD 250; N10-9 and N9-56 were both completed by the end of the 6th Century (Figure 3.1). The changes in the $\delta^{13}C$ record therefore match the archaeology record exactly. A pollen record from this core would confirm changes to the vegetation and therefore should be regarded as a priority for future research.

The record of percentage calcium carbonate provides further evidence that through time the inputs into the lagoon have changed. The times of variation in the $\delta^{13}C$ record match the times of change in the percentage calcium carbonate of the sediment. The drops of $\delta^{13}C$ are matched by drops in the percentage calcium carbonate and vice versa. The peak in the LOI record coincides with the key period of change in the $\delta^{13}C$ record, with the peaks in the $\delta^{13}C$ record being matched by troughs in the LOI. This suggests that the inputs into the lagoon during the building phases were affecting the sedimentary make up of the system. This shows that the different parts of the system are responding to perturbations which must be external to the system as they are all changing at the same time.

Deforestation is characterised by an increase in the C:N ratio (Kaushal and Binford, 1999). From the $\delta^{13}C$ record it appears that there are three main phases of deforestation in the catchment. The C:N ratio during zone 2 is lower than the

previous phase but there are two positive peaks. These coincide with the first and last increases in $\delta^{13}C$ at 175 and 90cm i.e. c.2200 and 1300 years BP. The second peak of $\delta^{13}C$ in zone 2 does not coincide with an increase in the C:N ratio and therefore may have a different causal mechanism. This is compounded by the fact that this second peak at c.1820 years BP or AD 227 is the only one that is picked up by the magnetic susceptibility record. This could be related to the fact that this temple is located right by the harbour and therefore sediment would have had a direct route to the lagoon and hence the enhanced magnetic susceptibility levels at this time. The other two temples must have been built in much more forested areas and therefore the predominant signal was that of sedimentalogical change. The C:N ratios also show that conditions are different from at any point in the past towards the present day.

The 'collapse' period equates to 82-46cm or c.1240-870 years BP (see Chapter 3). Although this is a peak in the $\delta^{13}C$ record it is not of the same level of magnitude as seen in the past. This suggests that this period was one of prolonged disturbance rather than severe disruption. This is backed up by the archaeological evidence as this was the period when the Ottawa Complex was being modified (see Chapter 3 and Figure 3.1). The two previous periods of change in zone 2 occurred over approximately 300 and 400 years respectively. This latter phase takes about 570 years. This is a big difference and is additional weight to the idea that this was a time of significant change in Lamanai. Archaeological evidence suggests that Lamanai was not affected by the collapse (see Chapter 3), the carbon isotope record in this study suggests that this was indeed a period of change which was of a different type and magnitude to that experienced in the past. The collapse is thought to have occurred at the same time as the late Holocene dry period seen throughout Central America. This time period in the $\delta^{18}O$ record in Lamanai does not reflect arid conditions, but this is the period of greatest stability in the sequence. The fact that this is not registered as a dry phase is not surprising because of the large size of the lagoon. The evidence from the sediments therefore suggests that the human activities in the catchment have left an imprint on their environment. The verification of the link between the archaeological and palaeolimnological records is reliant on further dating control and more evidence concerning the human society

such as population levels. The relationships discussed cannot therefore be regarded as proven.

Changes in the diatom record coincide with those in the isotope records. As described earlier the diatom record can be effectively split into two equating to pre- and post-human impact as determined by the isotope record. The period before human impact was one of high reconstructed conductivity and low species diversity. There is then a period where diatoms are not preserved. The XRD data shows this to be a period of increased aragonite in the sediment which may suggest dry conditions. The reconstructed conductivity decreases and species diversity increases after this point. The period from 82-46cm is a time of significant change to the diatom flora. The two species that dominate this zone are *Denticula elegans* and *Cyclotella plitvicensis*. The reconstructed salinity for this phase is not high but *Denticula elegans* is regarded as a high salinity species and is found in marsh environments. The ecology of *Cyclotella plitvicensis* is unknown and it is not found in the modern environments sampled in Belize. This alone implies that the environmental conditions represented in this zone are ones that are very different to the present day.

A scatter plot of $\delta^{18}O$ versus $\delta^{13}C$ (Figure 6.11) shows that all the points were found in the third quadrant. The inorganic carbon is therefore derived from plant material (as the $\delta^{13}C$ values are light) which adds weight to the argument that the $\delta^{13}C$ record is a reflection of the changes to the catchment's land cover over time. As there is not a correlation between $\delta^{18}O$ and $\delta^{13}C$ this suggests that the system does not covary and thus is not a closed system (Talbot, 1990). This is not surprising because it is a very large lagoon that is connected to the sea.

7.6 Outpost 2000 Results:

This Kullenberg core was taken from the same part of the New River Lagoon as Lamanai 1999 but approximately 1.5 km south in order to expand knowledge on the spatial variation in this part of the lagoon (Figure 7.1). The sequence is 73cm long

and samples were measured every 1-5cm. There is one radiocarbon date for this sequence:

Table 7.2

Code	Depth (cm)	Material	^{14}C Years BP	$\delta^{13}C_{PDB}$+/- 0.1	Calibrated Age	2 Sigma range
CAMS-77200	13	OM	360+/- 40	-29.9	AD 1491, 1603, 1609	AD 1442-1642

This core was analysed for carbon and oxygen isotopes in both the bulk carbonates and two gastropod species (*Cochliopina* and *Pygophorus* sp). The effect of analysing a single gastropod versus a sample from a mix of gastropods was also investigated in this core.

7.6.1 General Description:

The oxygen isotope record comprises very similar values to the Lamanai 1999 record (Figure 7.12). The Outpost 2000 oxygen isotope record begins and ends with the same isotopic value but between these two points are times of change. The most negative value is found at 13cm at -4.6‰. Two zones of more 'positive' conditions occur between 29-33 and 53-57 cm. The most prolonged period of change in the record is from 13cm to the top of the record, which shows increasingly 'positive' conditions. The rest of the record is either stable or demonstrates very short lived events.

The carbon record is rather more variable than the oxygen record and values above –4‰ are rare (which is in contrast to the record from Lamanai 1999) (Figure 7.12). There are three distinct sections. From the base of the record to 40cm the system is stable showing values of around -4‰. From 40 to 13 cm the record is very much more variable with values fluctuating between -4.4 to -6.6 ‰. From 13 cm to 5cm the values exhibit a negative trend reaching -8.1‰. This trend is then reversed and at the top of the record (3cm) values return to -4.9‰.

Although there appears to be an offset between the gastropod and the bulk carbonate records the same general pattern is apparent. The results within the gastropod data are much more consistent in the carbon data than in the oxygen data. This suggests that the two gastropod species analysed derive their carbon from the same source. The two points where the bulk carbonate and gastropod records are different are at positive peaks in the $\delta^{18}O$ record. This may be related to the habitat of the species as they may be differentially affected by water loss in the system i.e. the gastropods are buffered to change being able to move into deeper water at times of evaporation.

Outpost 2000 has been studied for both percentage calcium carbonate and magnetic susceptibility (Figure 7.13). The magnetic susceptibility record is comprised of all negative values suggesting that the core contains high levels of carbonates which might be beyond the machine's sensitivity. This is confirmed in the carbonate record as values are always greater than 74%. The carbonate record, although uniformly high can be separated into two zones. From the base of the record to 25cm the values are fairly stable. From 25cm to the top of the record the level of variability between depths is much greater.

7.6.2 Preliminary Analysis:

A scatter plot of $\delta^{18}O$ versus $\delta^{13}C$ shows that most of the values are clustered together and the record does not display covarience (Figure 6.11). The values plot in the same quadrant as Lamanai 1999. It is difficult to make any firm inferences from the gastropod data with regard to environmental change due to the low resolution of the record. What this record does neatly demonstrate is that different parts of an ecosystem will respond in different ways to the same forcing factors and thus the more proxies that are used the greater the overall ideas about the system will be.

In order to appreciate fully the changes that have occurred in the Outpost 2000 record they need to be placed in the context of the Lamanai 1999 record. The date for the Outpost 2000 core is 360 +/- 40 ^{14}C years BP at 13cm. The top of the Lamanai 1999 record has been estimated at approximately 400 years BP.

Based on extrapolation the 'collapse' period is equivalent to 31-45cm in Outpost 2000. This zone includes a negative excursion in the $\delta^{13}C$ record at 37cm or c.1020 years BP. Due to the proximity of this core to the shore (Figure 7.1) it is likely that this sequence, in a similar manner to Lamanai 1999, will be highly influenced by changes to the catchment. The isotopic shift that is seen in this zone is negative which may suggest a change in the inputs from the lagoon to the catchment from a deforested to an increasingly forested system. Outpost 2000 is at a higher resolution than the Lamanai 1999 and therefore it is not surprising that such a change could be picked up during this period. The Lamanai 1999 record shows sustained but reduced activity in the catchment as compared to previous periods. It could be postulated that this time period (c 1020 years BP) could be regarded as the time when the affects of the collapse were most keenly recognised in this area. The shift occurs from 40-35 cm or c.1100-970 years BP and is therefore not a very long-lived change to the system.

There were two further negative excursions in the $\delta^{13}C$ record at 29 and 21cm or c.805 and 580 years BP. These are short-lived events but they do provide evidence for catchment disturbance during this time frame. 13cm is approximately equivalent to AD 1640 which is when the site was abandoned by the Mayan people. From this point until 5cm there is a clear decline in the $\delta^{13}C$ values suggesting that this is the area recovering, undisturbed by settled people in the catchment. At 5cm (c. AD 1862) to the top of the record (c. AD 1917) these conditions are reversed. At this time a sugar mill was located at Lamanai and therefore was a period of environmental change (see Chapter 3). A sugar mill is likely to have a significant impact on the system due to the clearing of land for the crop, the increase in the amount of people living in the area and if processing occurred at the site, waste is likely to have been let out into the lagoon. Sugar cane is a C3 plant (T.Fallick pers.com, 2001) and 1862 is the most negative point in the $\delta^{13}C$ sequence. Further dating control is needed on this sequence to establish the exact timing of these events. If the $\delta^{13}C$ record is to be taken as a proxy to sugarcane activity then the present evidence suggests that this was fairly short lived. If diatoms had been

preserved during this time period this would have helped to quantify the type and magnitude of change to the system.

In general terms, the $\delta^{13}C$ record represents two phases in the history of the lagoon i.e. a stable to an unstable environment. This change occurred around 40cm or c.1100 years BP (AD 970). The record becomes more negative and variable from this point which suggests that there is either an increase in the amount of freshwater flushing through the system or an increase in the oxidation of organic matter. The timing of this change is very significant in terms of the human occupation of the area and adds to the evidence that this period was one of environmental change in this area of Belize.

There are two periods that stand out in the $\delta^{18}O$ record: 35-23cm and 13cm to the top of the record. The first period is equivalent to c.970-640 years BP is an extended 'positive' excursion where the least negative values for the sequence are found. This provides preliminary evidence for a climatic drying in the period leading up to the collapse. From 360 ^{14}C years BP onwards the $\delta^{18}O$ values are increasingly positive suggesting climatic drying towards the present day.

7.7 Summary of Lamanai, New River Lagoon

From the evidence that has been gained from this site a number of key conclusions can be made:

1. Both the diatom and stable isotope data from >3440-2200 years BP show fairly stable conditions. The diatom and $\delta^{18}O$ data suggests that the core environment was a littoral well vegetated zone and that the surrounding climate was moist.
2. The key period within which the lagoon appears to have undergone a significant transformation was between c.2200-2150 years BP. During this phase diatoms are not preserved, the $\delta^{18}O$ signal is a positive trend and there are sedimentological changes. It is during this period that the first peak in the $\delta^{13}C$ record occurs. This is at c.2180 years BP or 196 BC and coincides with a

building phase in Lamanai. This produced the largest Preclassic temple in Belize (N10-43).

3. The second event in the $\delta^{13}C$ record occurred from c.1900 -1400 years BP with a peak at c.1820 years BP or AD 277. This again equates to a building phase in Lamanai (temples P9-2 and P8-12). This is also a period of change in the diatom record with a drop in the reconstructed salinity and an increase in species diversity. Evidence of catchment disturbance is apparent during this phase.
4. The third peak in the $\delta^{13}C$ record is not as pronounced but it occurs over a much longer time interval than the previous events. This is from c.1240-870 years BP or AD 782-1192. During this period there was the most pronounced shift in the diatom flora and the $\delta^{18}O$ record indicates a drying climate.
5. This period of change is also noted in the Outpost 2000 record with a negative excursion in the $\delta^{13}C$ record centred on c.1100 years BP or AD 970. This is a higher resolution record and therefore it is not surprising that different signals would be picked up. The key point is that both records show this period to be a time of change. This is also the end of a positive phase in the $\delta^{18}O$ record for this sequence.
6. A drying trend is noted from c. 970-640 years BP which may represent the late Holocene dry period.
7. The Outpost 2000 record also shows preliminary evidence for catchment recovery from AD 1640 onwards (when the site was first abandoned) and possible evidence for disturbance between AD 1862-1917. This is when a sugar mill was operating at the site.
8. The climate shows evidence of drying from 360 ^{14}C years BP to the present day.

Lamanai, New River Lagoon

Basemap: DOS Sheets 15, Edition 5-GSGS (1993) & 10, Edition 5-GSGS (1994), Scale 1:50,000
Projection: Universal Transverse Mercator (Zone 16)

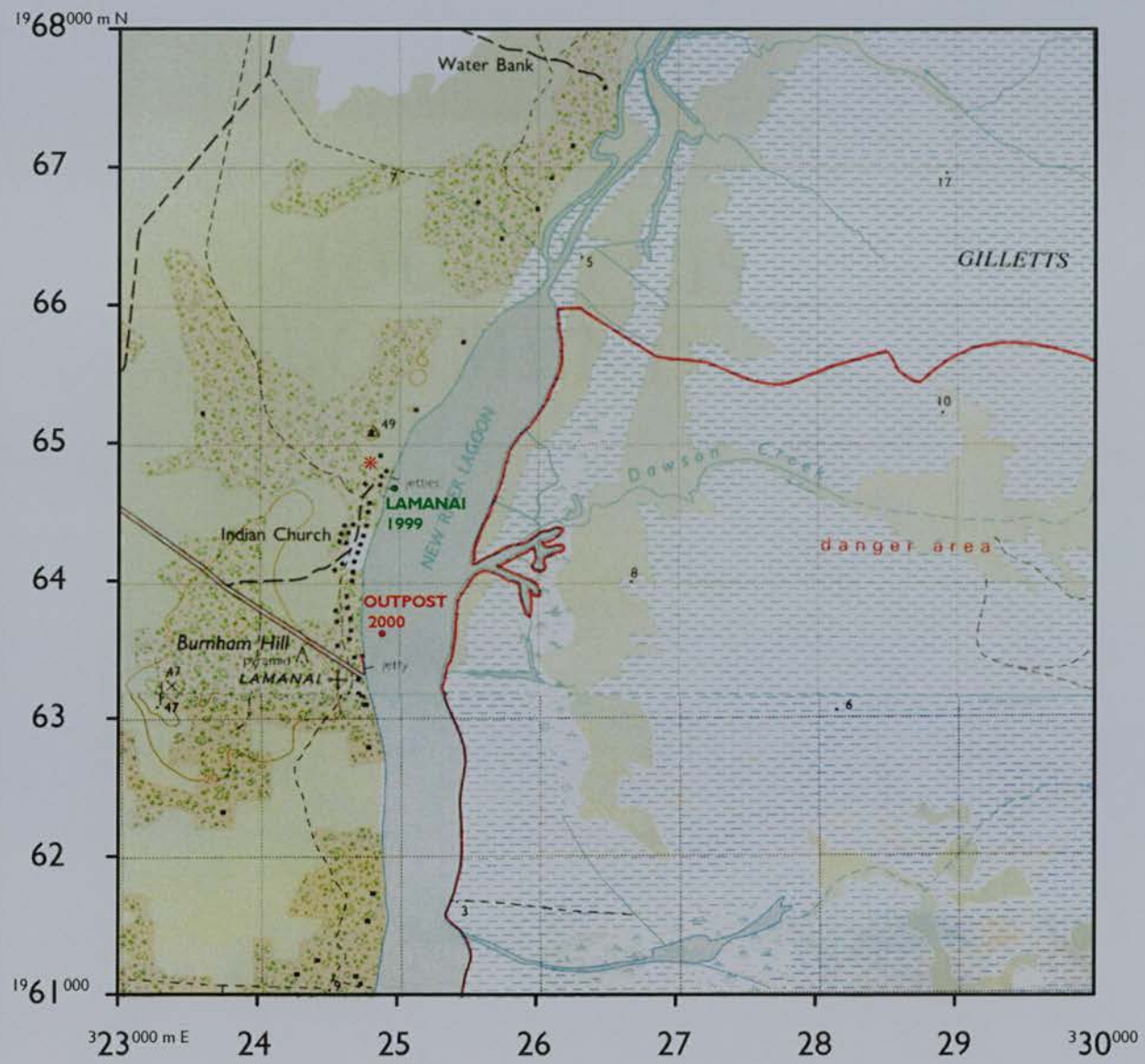
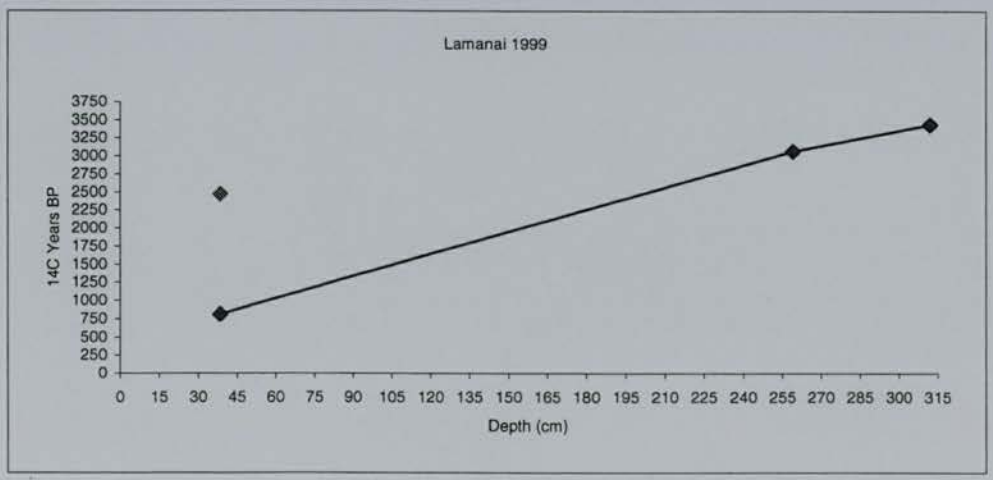


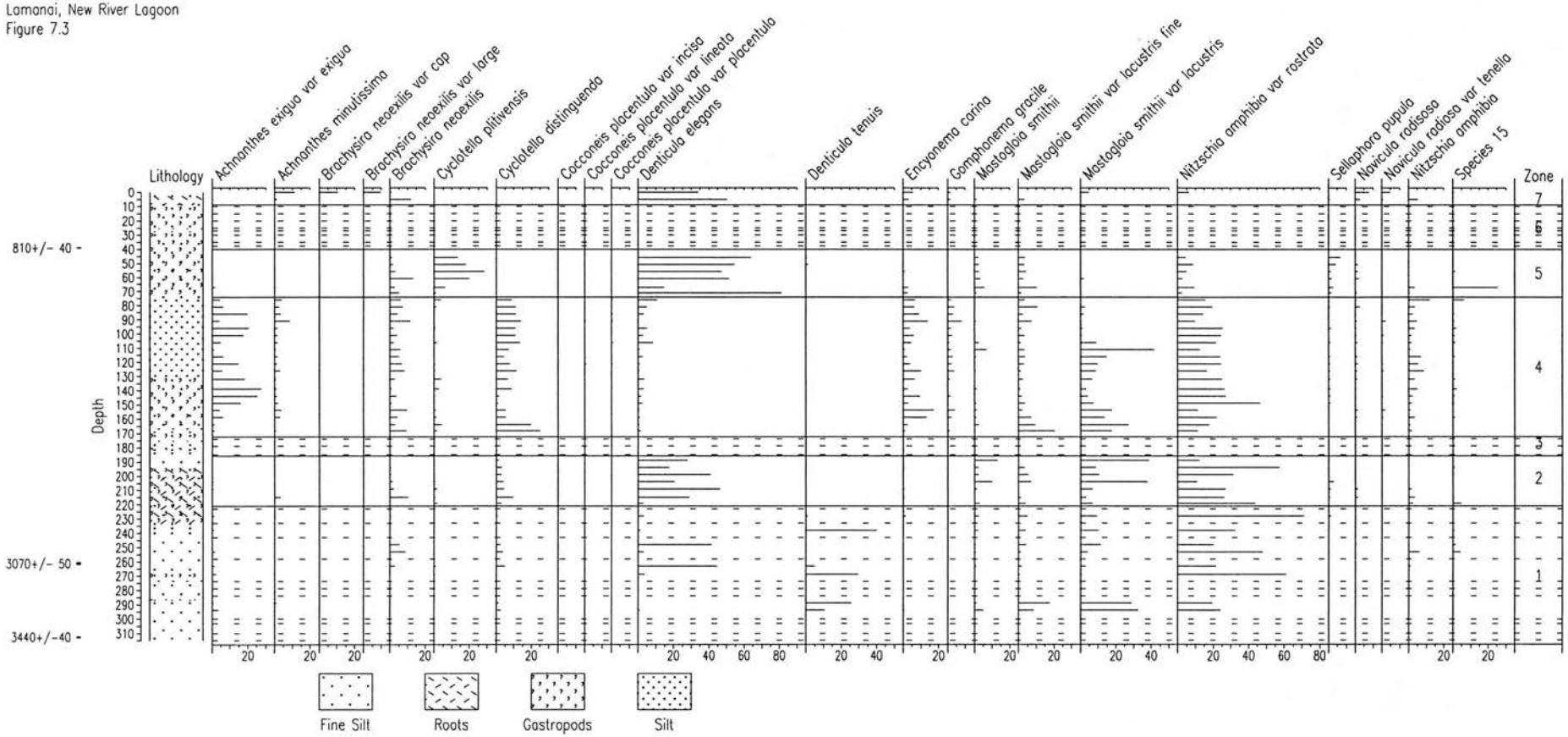
Figure 7.1
Modified from Murray (unpub.)

Figure 7.2 View from a Lamanai temple, looking south along New River Lagoon towards Hillbank.



Radiocarbon dates for Lamanai 1999. The points joined up are from terrestrial organic matter. The single point is the date from the gastropod. The error ranges can be found in Table 7.1.

Lamanai, New River Lagoon
Figure 7.3



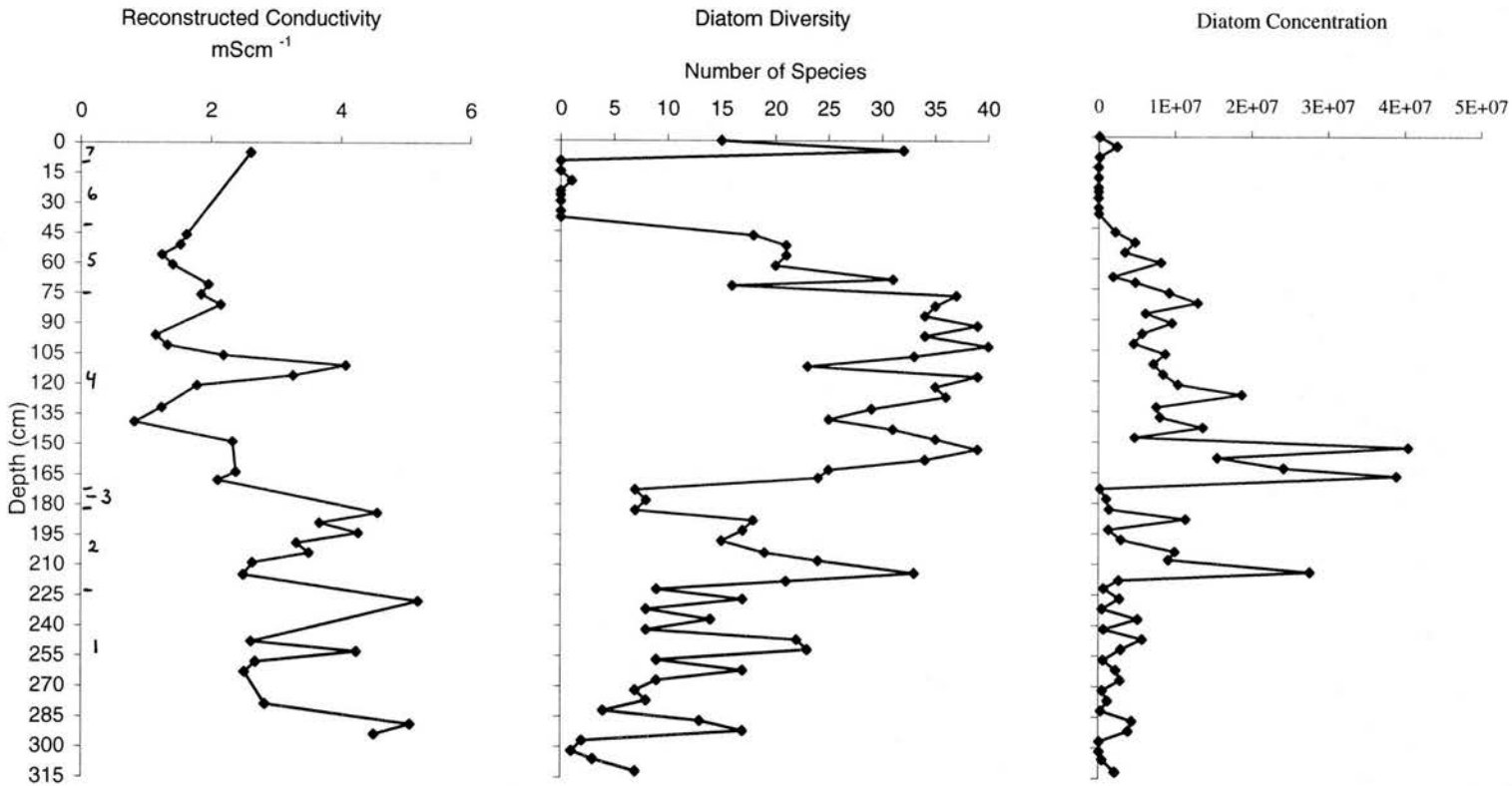


Figure 7.4 Lamanai 1999: Diatom diversity, concentration and reconstructed conductivity

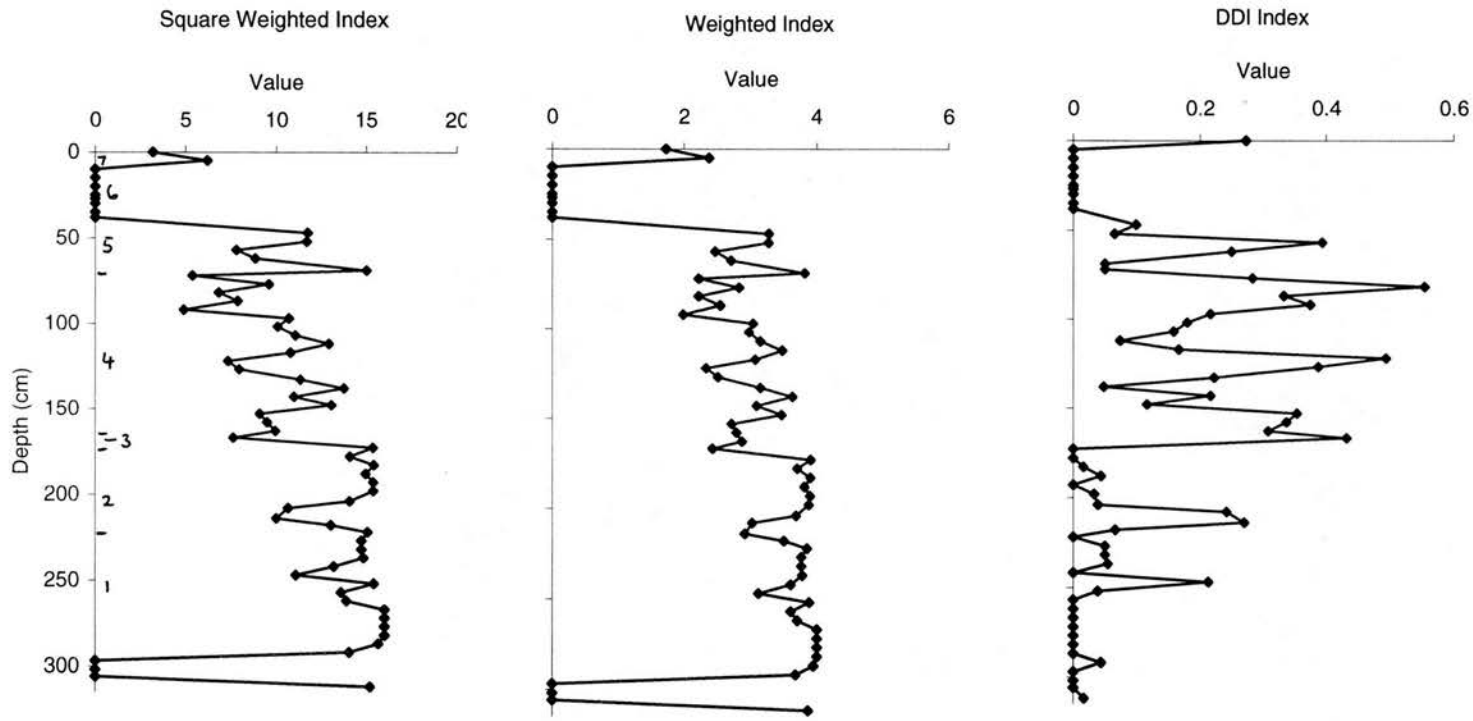
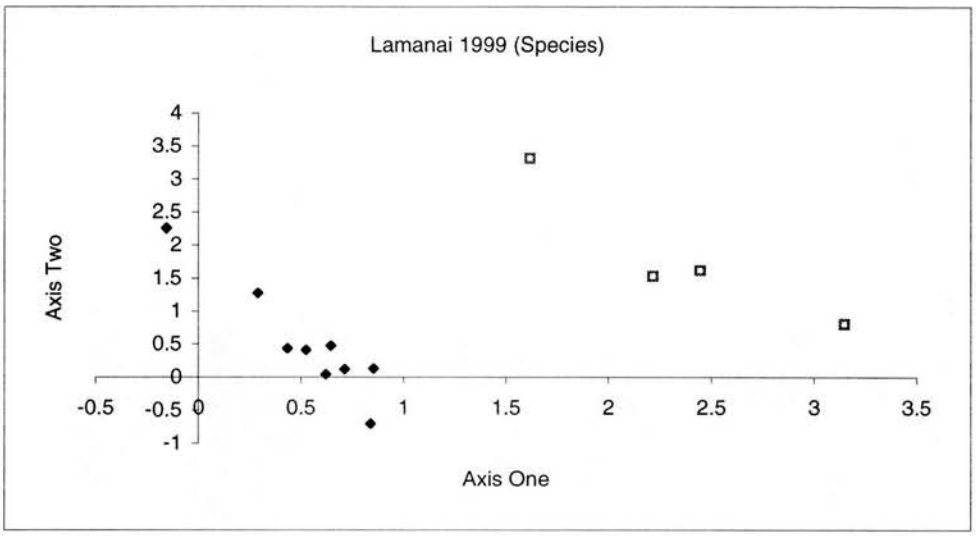


Figure 7.5 Lamanai 1999 Dissolution Indices



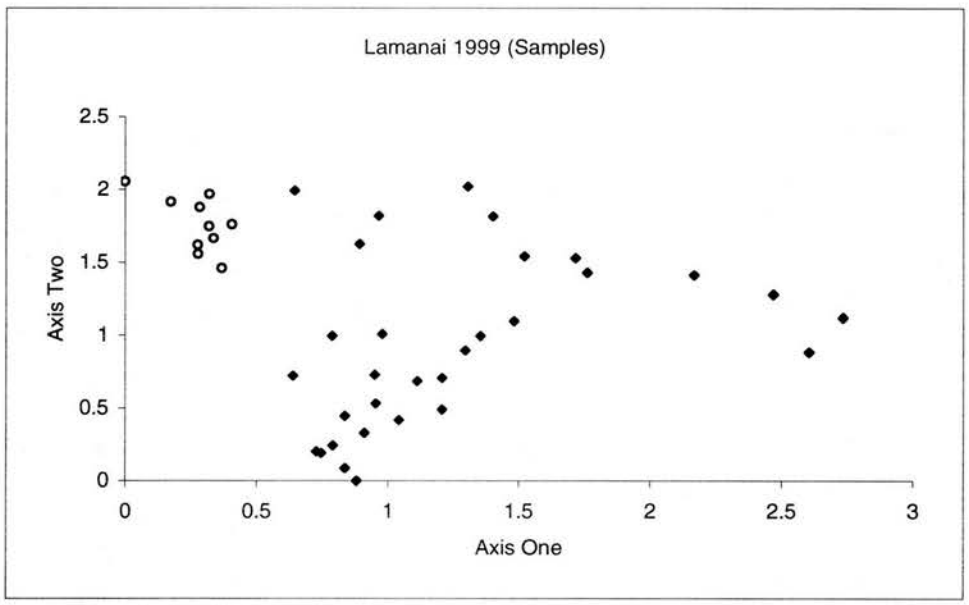


Figure 7.6 Lamanai 1999 Detrended Correspondence Analysis
The species fall into two groups:
1. *Achnanthes exigua*, *Brachysira neoexilis*, *Cocconeis placentula* var. *placentula*, *C.placentula* var. *incisa*, *Cyclotella distinguenda*, *Denticula elegans*, *Encyonema carina*, *Gomphonema gracile* and *Navicula radiosa* (diamonds).
2. *Denticula tenuis*, *Mastogloia smithii*, *M.smithii* var. *lacustris* (open squares).
The samples shown by open circles are those where *Denticula elegans* is extremely dominant as compared to *M.smithii* var. *lacustris*.

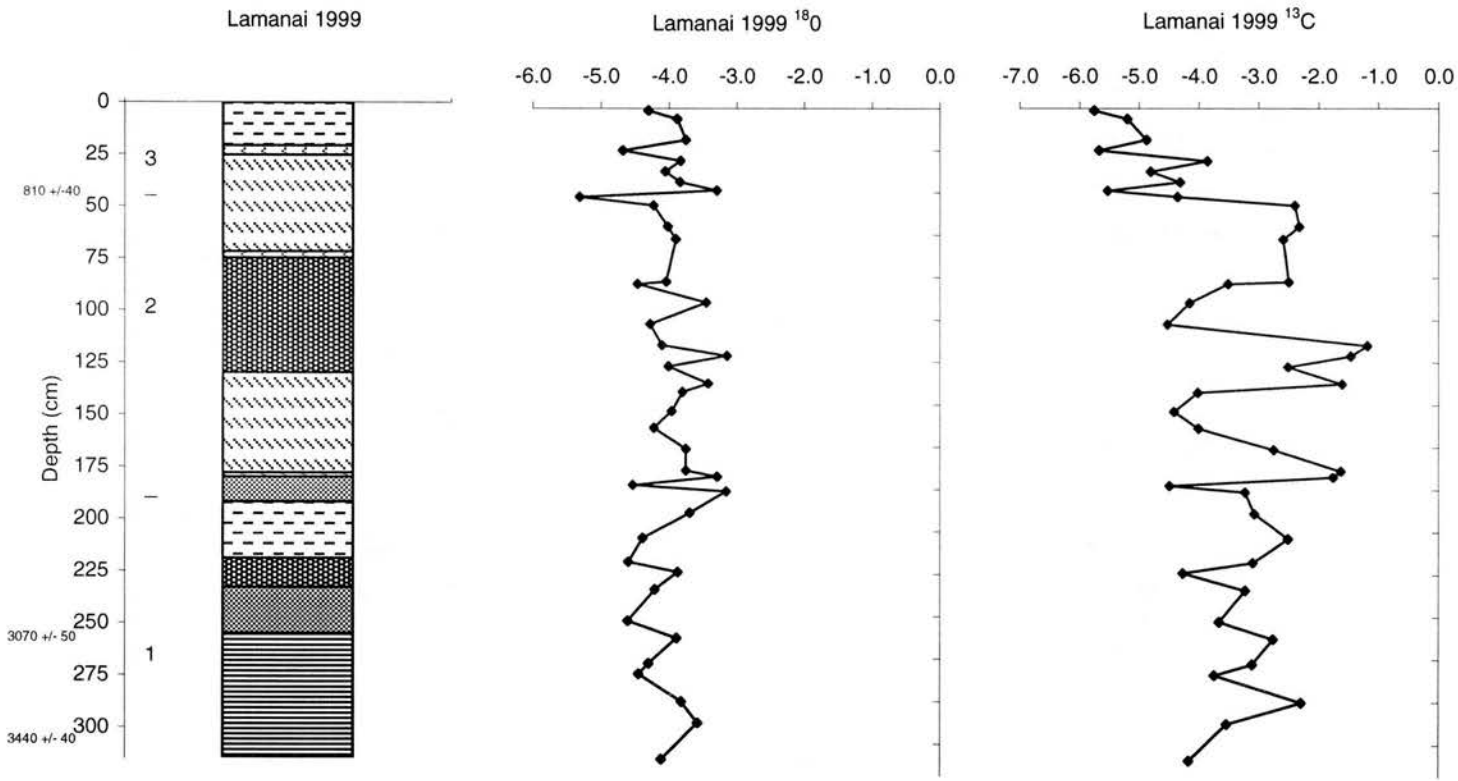


Figure 7.7 Lamanai 1999 ^{18}O and ^{13}C Records

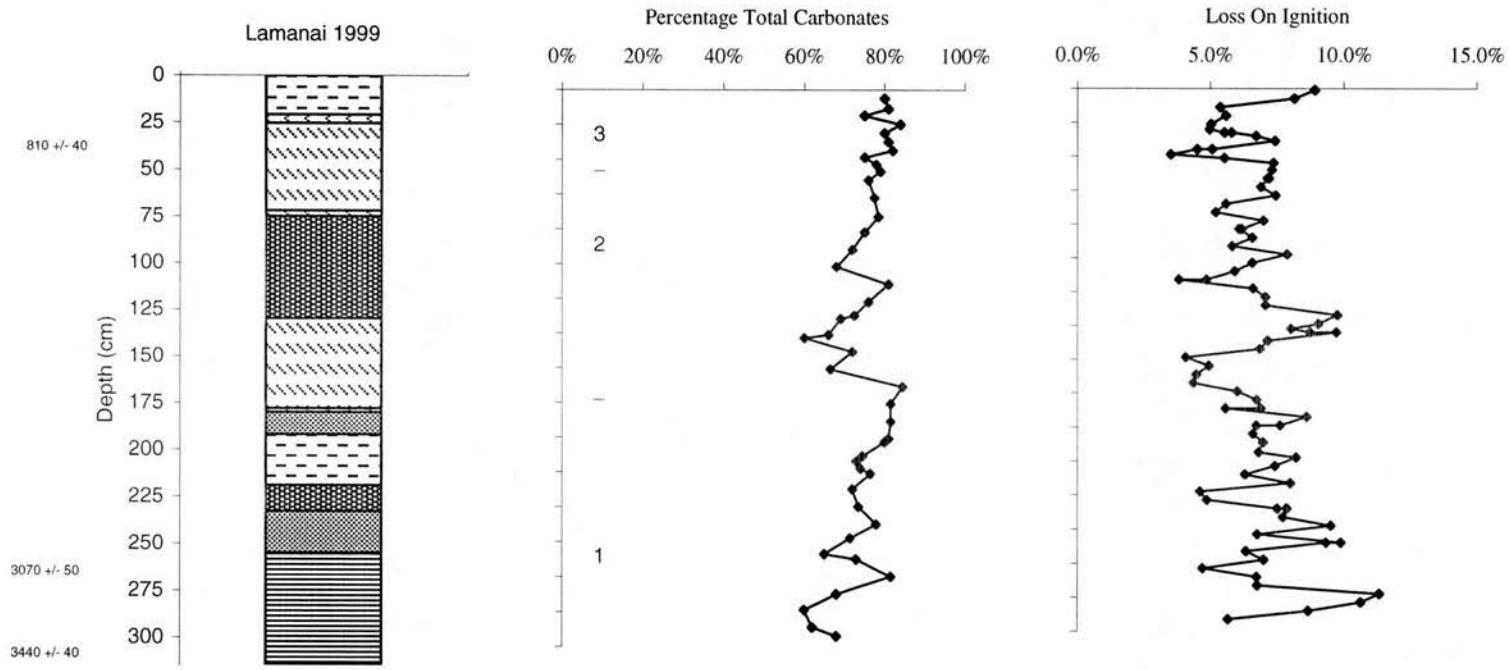


Figure 7.8 Lamanai 1999 Percentage Bulk Carbonate and Loss on Ignition

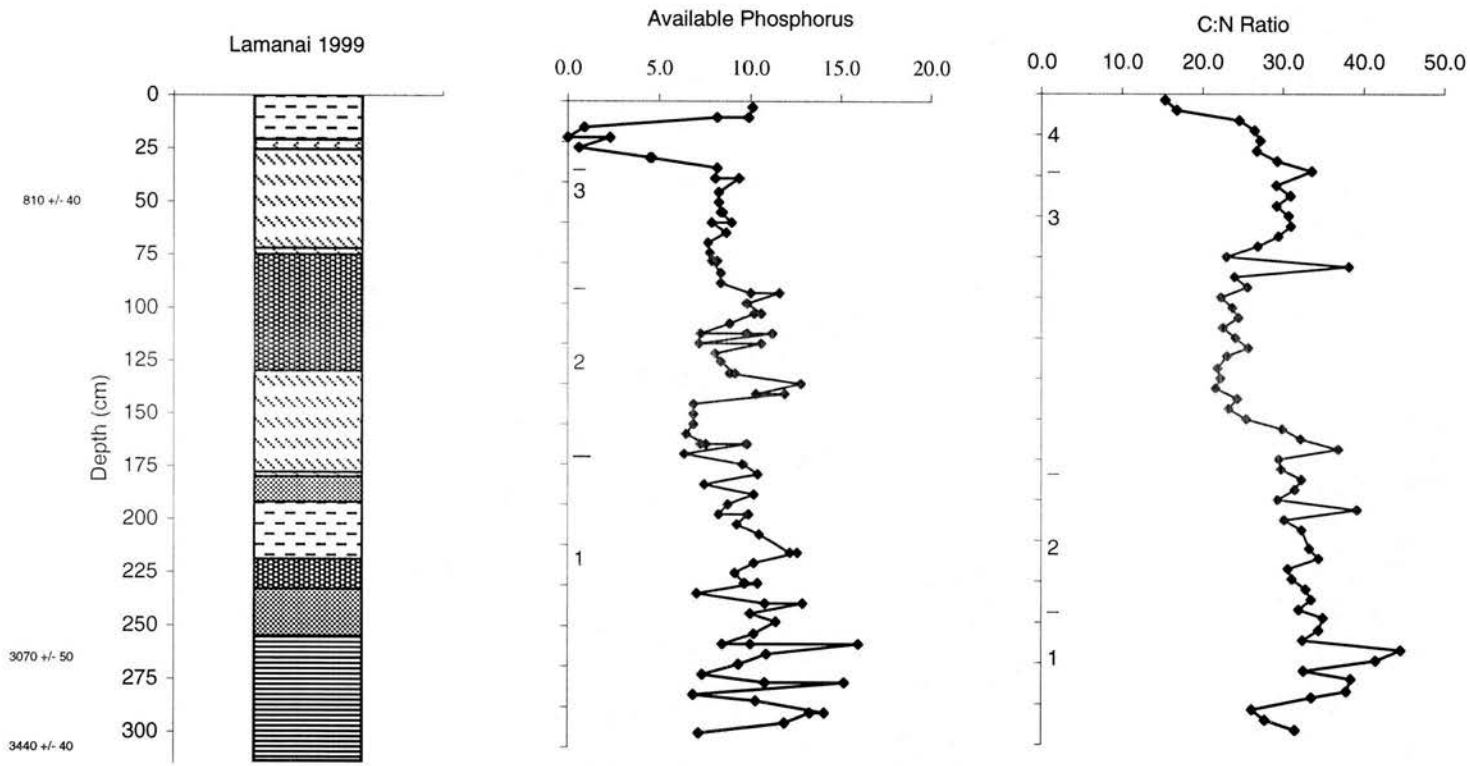
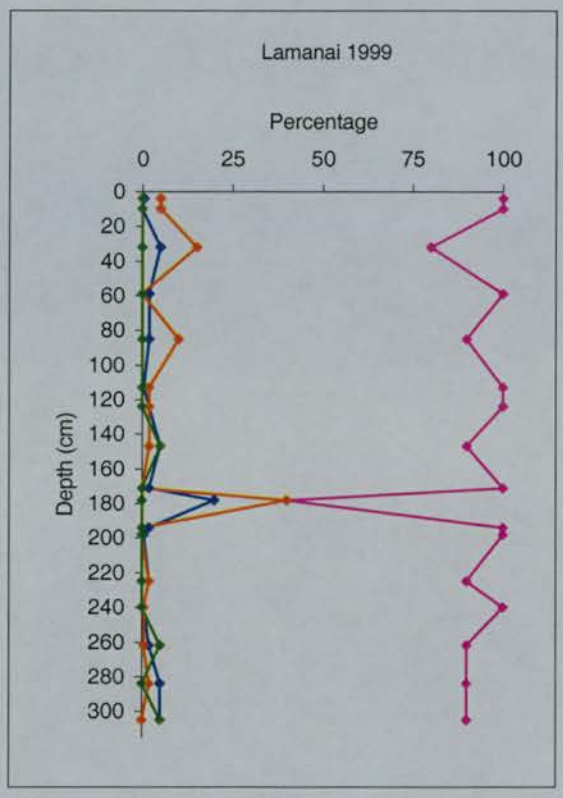


Figure 7.9 Lamanai 1999: Available phosphorus and C:N ratio results.

Figure 7.10



Key:
Pink: Calcite
Orange: Aragonite
Blue: Quartz
Green: Smectite

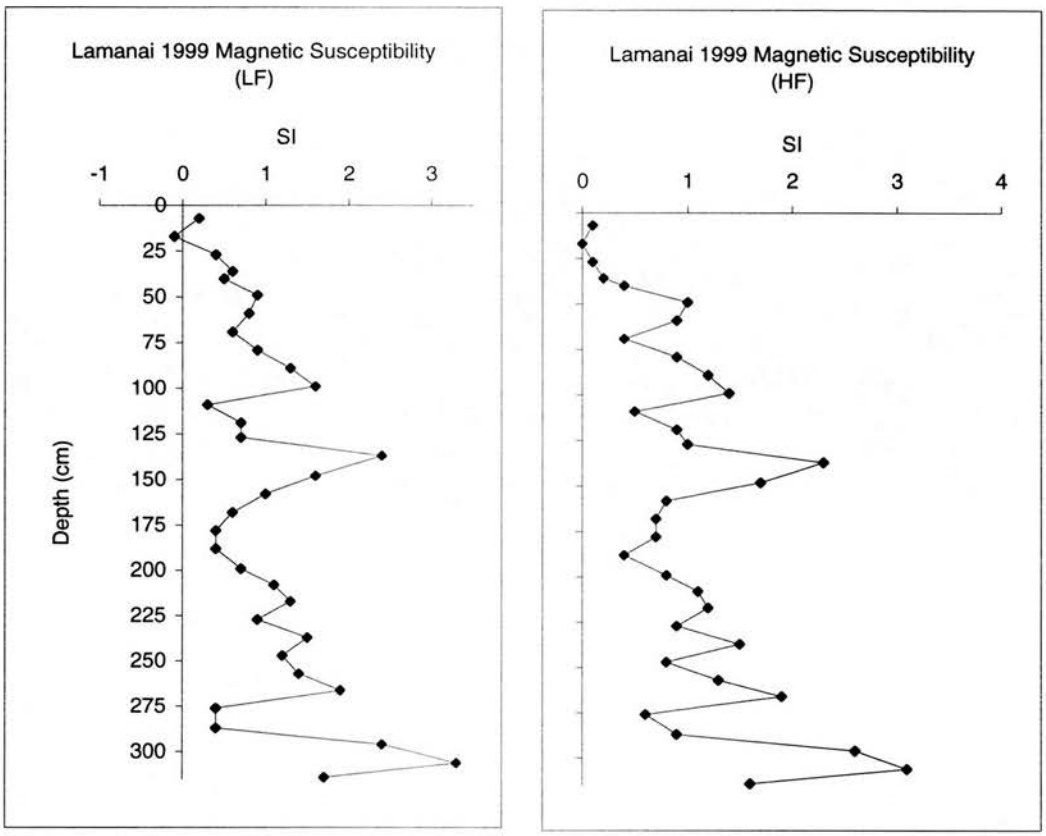
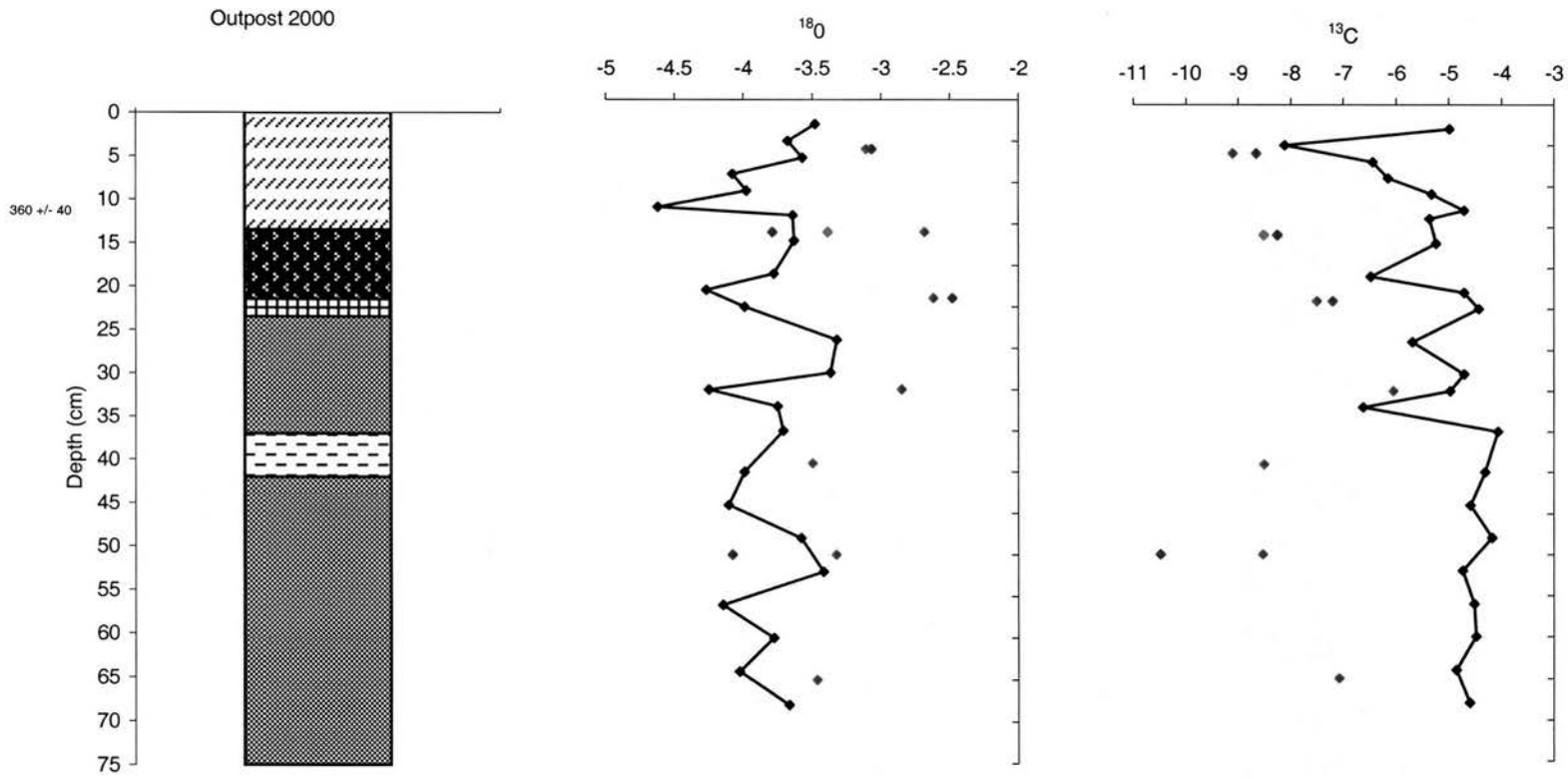


Figure 7.11 Lamanai 1999 Magnetic Susceptibility



Blue: Cochliopina sp
Green: Pygophoris sp
Red: Mix of Pygophorus sp

Figure 7.12 Outpost 2000 ^{18}O and ^{13}C Records

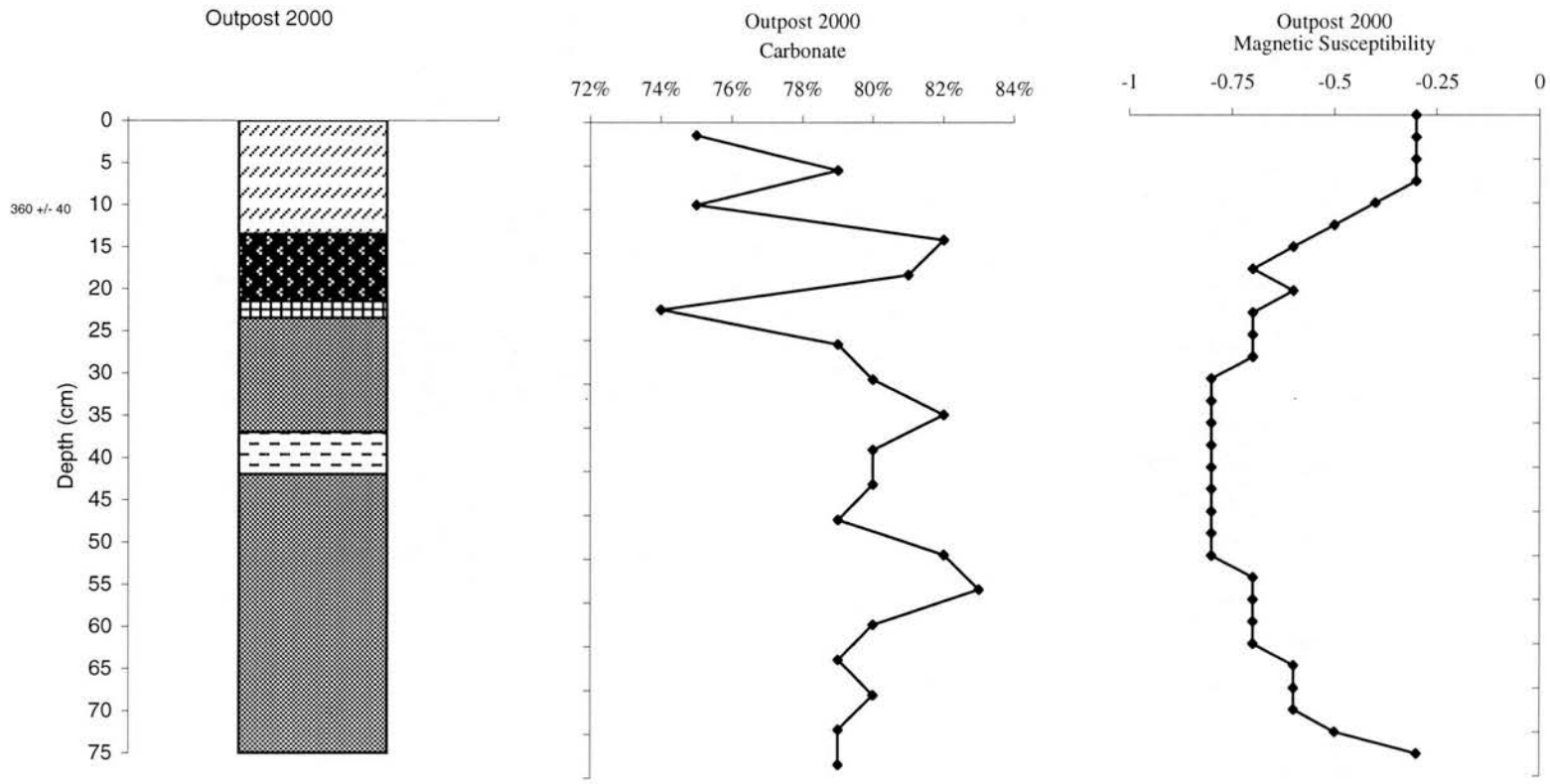


Figure 7.13 Outpost 2000 Bulk Carbonate and Magnetic Susceptibility

Chapter Eight: The Results from Honey Camp Lagoon

This chapter presents the results from Honey Camp Lagoon. Cores were collected over two field seasons (1999-2000) using all three coring methods referred to in Chapter 4. The locations of the cores are shown in Figure 8.1 and the stratigraphies are detailed in appendix 6.

8.1 Honey Camp Lagoon 1999

This core was taken from the edge of the southwest shore of the lagoon on solid ground (Figures 8.1 and 8.2). This is the first of four cores that were analysed from this lagoon.

Oxygen and carbon isotopes on both the bulk carbonates and two species of gastropod (*Cochliopina* and *Pygophorus* sp) were measured on this core. This record is 280cm long and has been analysed every 5-10cm. Three radiocarbon analyses have been made for this sequence:

Table 8.1

Code	Depth (cm)	Material	^{14}C years BP	$\delta^{13}C_{PDB}$ ‰ +/- 0.1	Calibrated age	2 sigma range
AA-45637 (GU-9580)	39	G	1670+/-45	-1.5	/	/
AA-39724	49	OM	Modern	-28.2	/	/
AA-39723	237	OM	Modern	-26.7	/	/

There is no clear reason why two of the samples would be modern and discussions with Dr. Charlotte Bryant at the NERC Radiocarbon Facility have not been able to resolve this. It is possible that the material sampled may not have been *in situ* to the core and therefore could have fallen into the core during sampling. Alternatively, the material sampled could have been root matter, although it did not have this appearance.

The date at 39cm is from gastropod and therefore will be affected by a hardwater error. This error can only be established by having dates from terrestrial organic

matter to compare with. A paired date was gathered from core L1 and is discussed in section 8.4. The hardwater error that was established from core L1 is 1105 years. The hardwater estimates from the two cores in New River Lagoon were comparable and because this is a much larger system it is feasible to apply the hardwater error calculated from L1 to Honey Camp Lagoon 1999.

The oxygen isotope record is much more variable than the records from the New River Lagoon (Figure 8.3). From the base of the record to 75cm the $\delta^{18}O$ values are variable but a prolonged trend is not apparent. The most positive point, in this part of the record, is at 260cm where values reach -1.3‰. The $\delta^{18}O$ record gradually returns to more negative values and stabilises around -3.5‰. From 140cm the record becomes more noisy which culminates in a negative peak at 70cm where values reach -7.5‰. This is a very short-lived event and by 65cm average trends have been restored. Levels fluctuate around zero to the top of the record. These are the most positive values in the whole sequence.

Gastropods are only present in the top 40cm of this core (Figure 8.3). The values recorded from *Cochliopina* sp and *Pygophorus* sp are both similar to the bulk carbonate record and to one another. The gastropod records are more variable than the bulk carbonate values. This is probably a function of the habitats in which they live and the shorter time scales that are represented by the shell data.

The carbon record can be split into three main zones (Figure 8.4). From the base of the record the carbon signal is extremely stable with the mean value being -10.3‰ and the standard deviation being +/- 0.6. At 70 and 55cm there are two short lived events which show a great depletion in the carbon values to -19.6 and -17.4‰ respectively. $\delta^{13}C$ then rapidly increases and is stable around 0‰ to the top of the record where there is a small positive peak from 25 to 15cm. Values from *Cochliopina* and *Pygophorus* sp. are consistently more negative than the bulk carbonate record apart from one value at the base (Figure 8.4). The *Cochliopina* sp.

record is the most variable and apart from at the top of the sequence, the species seem to be recording a similar signal.

The values found in the LOI record (apart from at the top of the record) are extremely low and do not reach higher than 5%. This is lower than the values seen in the Lamanai 1999 sequence. This is evidence that the two systems are different in their sedimentary make up. The Honey Camp record can be split into three zones which are based on clear shifts in the amount of organic matter that is present in the sediment (Figure 8.5):

Zone 1: Base – 252cm: Although this zone has a very small range of values there are fluctuations between depths.

Zone 2: 252 – 22cm: This is a very stable zone and levels are clearly lower than in the previous section. In a similar manner the values fluctuate between depths but within a very small range.

Zone 3: 22-0cm: The uppermost sediments show a massive increase in organic matter. This is a function of these sediments not being lacustrine (see stratigraphy in appendix 6 for details).

The particle size record can be divided into two zones (Figure 8.5). From the base to 131cm, the record fluctuates between high and low values. This variability suggests that inputs into the catchment are highly changeable. From 131cm onwards the record is very much less variable apart from a large peak at 60cm. This peak is of the same order of magnitude as changes seen lower in the core. The shifts in the mean particle size of the sediments suggests that the inputs into the lagoon have changed over time. This matches the XRD record which switches between quartz and calcite domination in the first half of the record before becoming much more stable. In this stable section, quartz dominates. Levels of calcite increase at the same time as the major negative excursion in the isotope records at 70cm (Figure 8.6).

The magnetic susceptibility record is quite different from the rest of the proxies (Figure 8.7). There are two clear peaks at 280-260cm and 195-187cm. From 160cm

to the top of the record the values of magnetic susceptibility are very much lower. This record is not mass specific and therefore cannot be compared to the other magnetic susceptibility records.

The percentage calcium carbonate record has two phases (Figure 8.7). From the base of the record to 160cm the values climb steadily from 0% to 80%. By 152cm the levels have dropped to 8% and remain low until 101cm where values reach 49%. This is a short-lived peak and levels have dropped to low values by 99cm. Values remain low until 50cm after which they increase to 40% by the top of the record.

From the base to 256cm of the available phosphorus record (Figure 8.8), the values follow a declining trend. From 256-211cm values rise and fall in a concave pattern. There is a peak in available phosphorus at 206cm (6.3 ppm) but these have dropped by 198cm. From 193cm upwards, values although fluctuating, are very stable and low. Values rise to 5 ppm at 53cm falling gradually to 18cm. From then on they rise rapidly to the top of the sequence and at 8cm the highest values in the sequence are found at 8.1 ppm. This rise at the top of the sequence is very similar to the pattern exhibited in Lamanai. Throughout the whole sequence of Lamanai values are much higher than those in Honey Camp Lagoon.

The C:N ratios of the sediment are extremely variable in this sequence fluctuating between very high (150) and low values (0) (Figure 8.8). This suggests that the inputs into the system have been extremely variable through time. This is most apparent in the lower half of the record from the base to 128cm. This matches the enhanced variability of the particle size record in this period and is further evidence that the inputs to the lagoon were different in this period to more recent times. The limiting variable in this sequence is nitrogen.

8.2 Preliminary Analysis:

For the purposes of comparison and in order to create a preliminary chronology for this record, a constant sedimentation rate was assumed through time. The problems of doing this are highlighted most clearly in Figure 6.3. Due to the paucity of dates from this record it was decided that this was the best strategy to employ because it provides the basis for comparing between records. The extrapolated dates should therefore be treated with caution. All the dates referred to have been corrected for the hardwater error of 1105 years after the extrapolations took place.

The base of the isotope record is 280cm which equates to 10,900 years BP. From this it appears as if this record covers the same time period as Hillbank 1998. This raises a number of important points:

1. Both Hillbank 1998 and Honey Camp Lagoon 1999 cover approximately the same period of time even though they are very different lengths (2.8m as compared to 14m).
2. The signal for the Lateglacial in Hillbank 1998 represents the driest conditions seen in this record. The base of Honey Camp 1999 (280-240cm) is also drier than the main period of the sequence (240-75cm) but this period of time does not represent the driest conditions seen in this record (40-0cm). The two periods of time where conditions are thought to have been dry in Central America are during the Lateglacial and the late Holocene. The Hillbank 1998 core does not cover this latter period. It is likely that the late Holocene dry period is covered by the top of the Honey Camp Lagoon sequence. This will therefore allow a preliminary assessment to be made concerning the relative severity of these events.
3. Both records demonstrate a stable climate for the main period of the Holocene (240-75cm or 9200-2100 years BP). The values that are seen in the $\delta^{18}O$ sequence from the base of the record to 75cm in Honey Camp Lagoon 1999 are very similar to those in the New River Lagoon (Honey Camp average: -3.7‰; Lamanai average: -3.9‰; Hillbank average: -3.5 ‰). This suggests that during this period the systems were more similar than they are today.

From the base of the record to 130cm (c. 4500 years BP) the particle size and C:N ratios are at their most variable. All this evidence points to this period being one where the system is most influenced by the catchment rather than within-lagoon processes. If the lagoon was an open system through the main period of the record (like the New River Lagoon) then the inputs into the lagoon would be very dependent on the inputs provided by rivers and the surrounding marshland. These are likely to be changeable which therefore accounts for the variable particle size and C:N ratios in the first half of the record. This is also shown in the XRD results which show a great deal of variability during this period between the amount of quartz and calcite in the sediment.

The magnetic susceptibility record suggests there were two key disturbance events in the catchment at 192 and 280-260cm. The latter peak coincides with the most positive signal in the $\delta^{18}O$ record at the base of the sequence and dates to approximately 10,900-10,000 years BP. The second peak dates to approximately 7100 years BP. Changes in the calcium carbonate or XRD records do not match those in the magnetic susceptibility. This suggests that the peaks are not due to changes in the type of sediment entering the system as has been noted in the records from the New River Lagoon.

The negative shift at 70cm is very significant and it represents the systems ability to rapidly change. Its importance is accentuated because the system does not return to its previous $\delta^{18}O$ condition and enters a new state, which is totally different from that experienced in the past. The shift at 70cm occurs at approximately 1900 years BP. One issue that is not clear concerning Honey Camp Lagoon is its past connection to the sea (see Chapter 4). 70cm could perhaps mark an event which led to the closure of the lagoon resulting in an isotopic signature much higher and more sensitive to change i.e. what one would expect from a closed system. The 70cm event could be a flooding of the system as a result of the closure of Freshwater Creek which may have

temporarily increased the water volume in the lagoon. This is supported by the two negative excursions in the $\delta^{13}C$ record.

The $\delta^{13}C$ values exhibited in this record are very different from those in the New River Lagoon. In comparison levels are very depleted which could be for a number of reasons:

1. Groundwaters from well-vegetated catchments are more influenced by the decomposition of isotopically light plant material than those from drier, thinly vegetated catchments. The former tend to produce runoff with more negative $\delta^{13}C$ than the latter (Talbot, 1990).
2. Climatically induced floral differences (e.g. the shift from C3 dominated to C4 dominated systems) will also influence the $\delta^{13}C$ of the inflow producing isotopically negative inflow from humid catchments.
3. High level of oxidation of organic matter which results in high levels of ^{12}C in the TDIC pool. The atmosphere has a $\delta^{13}C$ of -7‰ and at the surface water interface (at approximately 20°C) this carbon will be transformed to bicarbonate and then precipitated to carbonate. This will be in equilibrium with the atmosphere and will therefore have a ^{13}C value of 0‰. The highly negative carbon values suggest the carbon being measured has been oxidised from organic matter.
4. The two very negative shifts could represent times when the carbon has been completely derived from aquatic plants. This is not however reflected in the C:N ratios.
5. High rates of flushing also explain low carbon levels as the TDIC would not have time to equilibrate with atmospheric CO_2.
6. There must have been a change in either the source or the mix of sources to result in the base of the carbon record being so stable and the top so variable. The change in the system at 70cm must therefore be a very significant time in the history of the lagoon.

On the $\delta^{18}O$ versus $\delta^{13}C$ plot there is a correlation between the two variables with an R^2 of 0.6622 (Figure 6.11). The data does not form a continuum along this line and appear to be composed of two separate populations. This relationship is driven by the significant difference between the top of the record and the rest of the sequence. This is therefore clear evidence in favour of the idea that the event at 70cm resulted in the lagoon taking on a very different form.

The shift to the most positive $\delta^{18}O$ conditions begins at 55cm or c.1200 years BP. This is an isotopic shift of 2.8‰. This is highly significant and coincides with the late Holocene dry period.

8.3 Honey Camp 2000 (L4)

Core L4 is located near the western shore of the lagoon, north of the Honey Camp Lagoon 1999 core (Figure 8.1). It is a 38cm Livingstone core taken in approximately 8 metres of water. L4 has been analysed for oxygen and carbon isotopes in both the bulk carbonates and *Pygophorus* sp. measured every 1-2cm. Diatoms were not preserved in this sequence.

Due to the unconsolidated nature of the sediments in the New River Lagoon the cores retrieved all covered different time periods. The sediments in Honey Camp Lagoon are much more coherent and therefore it is more likely the cores will cover much more similar time periods. The top sediments in Honey Camp Lagoon are a very fine material with scattered gastropods. This extends for 12cm in Honey Camp 2000 (K), 3cm in L1 and 1cm in L4. The records may therefore only be slightly offset.

Table 8.2

Code	Depth (cm)	Material	^{14}C years BP	$\delta^{13}C_{PDB}$ ‰ +/- 0.1	Calibrated age	2 sigma range
AA-45636 (GU-9579)	17	G	3705 +/- 55	-4.4	/	/

The implications of this date will be discussed further with core L1.

8.3.1 General description:

The oxygen isotope record is stable with all the values falling close to zero apart from a positive excursion to 1.5‰ at 14cm (Figure 8.9). These values match the top of Honey Camp 1999. The excursion at 14cm is a very significant change in the system although it is short lived. Limited *Pygophorus* sp. shells were analysed from this core and these show a large offset from the bulk carbonate record. This core was taken from the main body of the lake and this species is generally found in littoral environments and thus the offset could be a function of the different environments the two records represent.

The carbon isotope record is much less spiky than the oxygen isotope record, but in a similar manner to Honey Camp 1999 the values fluctuate around zero (Figure 8.9). Similar to the oxygen record, the *Pygophorus* sp. record is offset with the values being consistently more depleted than the bulk carbonate record and exhibiting a larger range of values. This is most likely to be a response to the different carbon sources which would be available to the gastropods. Both the carbon and the oxygen records from 10cm to the top of the record are very stable which suggests the very recent past in Honey Camp Lagoon has been so.

Figure 6.11 is a scatter plot of $\delta^{18}O$ versus $\delta^{13}C$. These two variables are not correlated but the values are scattered in all four quadrants suggesting clear changes have occurred throughout the core's history. The removal of the outlying point at 14cm does not alter this.

L4 has also been analysed for percentage calcium carbonate and magnetic susceptibility (Figure 8.10). The carbonate record is fairly steady apart from a sharp temporary drop in levels at 22cm to 20% from approximately 75%. Levels remain fairly steady apart from a further small drop at 12cm. The amount of variability is less in the top half than in the bottom half of the core. The magnetic susceptibility

record can be separated into three phases. From the base of the record to 27cm the values gradually decline, this is reversed between 27-17cm. Values drop by 15cm and from this point to the top of the record values increase to the highest in the sequence. The highest value is found at 2cm reaching almost 1Si.

8.3.2 Preliminary Analysis:

As described earlier if the system is in equilibrium with the atmosphere it will therefore have a $\delta^{13}C$ value of 0‰. If this holds true then the $\delta^{18}C$ of the water should be 0‰ unless it has been enriched through evaporation. The key episode of change in this sequence is at 14cm. This is significant because it is the largest excursion in the sequence, representing an isotopic shift of 2.6 ‰. The oxygen isotope signal at this time therefore represents a time of enriched evaporation and the carbon record has higher levels of $\delta^{13}C$ which can indicate atmospheric exchange or increased aquatic productivity.

8.4 Honey Camp Lagoon 2000 (L1)

This core has been analysed for oxygen and carbon isotopes and is located approximately 700 m north of core L4 (Figure 8.1). It is 36cm long and has been analysed every 1-2cm. Three radiocarbon dates have been obtained for this sequence:

Table 8.3

Code	Depth (cm)	Material	^{14}C Years BP	$\delta^{13}C_{PDB}$‰ +/- 0.1	Calibrated Age	2 Sigma range
AA-42419	19	OM	3315+/- 53	-28.2	1604 BC	1738-1455 BC
CAMS-77199	19	G	4420+/- 40	-3.5	/	/
AA-42418	7	OM	764+/-37	-27.7	AD 1276	AD 1214-1295

From the paired date at 19cm the hardwater error for Honey Camp Lagoon is 1105 years. This is 422-555 years less than in the New River Lagoon, but is in the same realm suggesting that there is a consistency throughout this region.

The oxygen record shifts from positive values from the base of the core to 19cm and then to negative values to the top of the sequence (Figure 8.11) within a range of $\delta^{18}O$ values between 0.58 and -0.65‰. Both *Cochliopina* and *Pygophorus* species were analysed in this core. The differences in oxygen isotope values between these two species is marked at the top of the core but diminishes towards the base, suggesting that the relationship between these two species has changed over time. The *Cochliopina* species used in this record were very small and thus they may have been juvenile. The record from gastropod shells is time averaged over their life cycle and therefore a younger specimen may not be recording the same time period as an older one and thus the records may not be comparable.

The carbon isotope record shows the opposite trend from the oxygen isotopes, moving from negative values at the base to positive values at the top of the core (Figure 8.11). The switch over occurs at the same point in the record at 19cm suggesting that this is a significant time in the sequence. The range of values is large from -3 to +2‰ which is greater than in L4. The gastropod species are consistently more negative than the bulk carbonate results and the offset between the two species is much less than in the oxygen record. This suggests that the two species have similar carbon sources which is a factor that is unlikely to vary through a life cycle.

Both percentage calcium carbonate and magnetic susceptibility (Figure 8.12) have been measured for this sequence. The magnetic susceptibility record is similar to that produced for L4 although they cannot be strictly compared because they are not mass specific records. The base of the record is negative and values rise to a peak by 17cm and drop by 15cm. From 15cm to the top of the sequence values rise steadily. The calcium carbonate record can be divided into two halves with the base of the record to 21cm being stable, apart from a peak in values at 33cm. From 21cm to the top of

the record the values follow a concave pattern before increasing from 5cm to the top of the sequence.

C:N ratios have been determined for this core and values are stable at around 17 apart from an excursion between 20-5cm (Figure 8.12). Values increase to the top of the record. During the excursion, the inputs into the system are from terrestrial organic matter. For the rest of the sequence values are intermediate between algae and land plants suggesting that both are contributing to the system. This matches the $\delta^{13}C$ record which switches from negative to positive values and back to negative at the top of the record. The positive phase coincides with the increase C:N ratio levels at 16cm which is a signal from terrestrial plants entering the system. An increase in $\delta^{13}C$ implies either an increase in aquatic photosynthesis (which does not tally) or a change in the inputs to the catchment.

8.4.1 Preliminary Analysis:

In terms of the stratigraphy for L1 and L4 two points are important to help in the understanding of how the two cores match together. Firstly, as has been explained earlier there is more of the top sediment in L1 than L4 which suggests that L4 is approximately 2cm offset from L1. Both records demonstrate a clear banded structure, but the L4 sediment is much more detailed suggesting that the sedimentation rate in this part of the lagoon is higher than in the L1 region or it is more variable.

The base of both L1 and L4's $\delta^{18}O$ record are characterised by short excursions, both following the same positive to negative trend. The records are approximately 2cm offset and thus the large positive excursion in L4 between 15-13cm is matched by a small positive excursion in L1 between 17-14cm. The L4 excursion occurs during a pale sedimentary band in the sediment. The previous positive excursions at 22 and 28cm in the L4 record also occur in pale bands. These bands are not present in the L1 record suggesting that the signal may be dampened.

The $\delta^{13}C$ record in both sequences is less variable than the $\delta^{18}O$ sequences. The record from L4 is much more changeable and does not display the clear trend seen in L1. There is a clear change in L1 between 17-14cm and this is matched in L4 with a similar positive trend from 15-13cm. A positive signal in $\delta^{13}C$ implies there has been an increase in CO_2 exchange with the atmosphere. This occurs at the same time as a positive excursion in the $\delta^{18}O$ record. The synchronicity of both isotope changes in both cores is clear evidence that this represents a drying event. This is supported by the similarity between the two magnetic susceptibility records from L4 and L1 which suggests that this proxy is responding to changes in the catchment. This is further evidence that the two core locations have been influenced by the same environmental changes through time.

L1 has two dates which are surprisingly old for the length of sediment retrieved. There is both an organic matter and a gastropod date at 19cm. The date from L4 at 17cm is 2600 years BP when it has been corrected for the hardwater error. This is comparable with L1 and confirms that the records are approximately 2cm out of phase. It is possible there could be a break in the sedimentation between 7 and 19cm. There is however no obvious point in the sedimentary record where this could have occurred apart from a section of fine organic bands around 17cm in L1 which may indicate shallowing (S.Metcalfe, pers.com., 2000). Both records therefore have evidence for a dry phase and if this was severe enough it could have resulted in a dramatic decrease to the lagoon's sedimentation. In order to determine whether or not this is the case, very close interval sampling as well as dating would have to take place. This however would prove difficult with these cores due to the lack of terrestrial organic matter available in the sediment. Gastropods could be dated but the one paired date would not be sufficient to apply a correction factor when such high resolution information would be required.

The drying event in cores L1 and L4 can therefore only be ascribed with any certainty to be older than 764 ^{14}C years BP which means that it could be a signal from the late

Holocene dry period. The period of time where the driest conditions are noted in the Punta Laguna record are 1785-920 ^{14}C years BP with maximum conditions occurring between 1225-930 ^{14}C years BP (Curtis *et al.*, 1996).

The human occupation of Honey Camp Lagoon is thought to have occurred in two phases:

1. Postclassic: AD 1100 onwards (940 years BP onwards).
2. Terminal Classic/early Postclassic: AD 750-1100 (1300-940 years BP)

The dates were converted to radiocarbon years according to Stuiver and Pearson (1993).

It could be postulated that these two communities centred around the dry phase seen in the record but this cannot be substantiated with the evidence available.

The scatter plot of δ^{18}O versus δ^{13}C for L1 has an R value of 0.6128. This is highly significant (Figure 6.11). This suggests the shift from positive to negative values in this sequence is a real trend and represents a shift over time in the dynamics of the lagoon. The most interesting point is that this is not so clear in the record from L4. This is most likely to be due to core location. L1 was taken from a narrower portion of the lagoon and therefore it could be argued this would be a more sensitive area to change.

8.5 Honey Camp 2000 (K)

This Kullenberg core was taken from the same position as L1 in Honey Camp Lagoon (Figure 8.1). The core was analysed for oxygen and carbon isotopes in both the bulk carbonates and gastropod species. The species analysed were *Cochliopina* and *Pygophorus* sp and the latter was investigated for the difference between a single gastropod and a mix of specimens in a similar manner to Outpost 2000. This record is 78cm long and was analysed every 4-13cm. Diatoms were not preserved. There are at present no dates from this sequence.

The analyses for this core are at low resolution and therefore the changes in the system may in reality be more complicated, but it does give an idea as to the general changes that have occurred in the most recent period of Honey Camp Lagoon's history. The $\delta^{18}O$ record comprises mainly slightly negative values with two positive excursions at 40 and 10cm (Figure 8.13).

Cochliopina and *Pygophorus* species were both measured in this core (Figure 8.13). With the latter species both a single specimen and a sample from a mix of specimens was analysed. The relationship between the species is not consistent through time. At the base of the record the mixed *Pygophorus* assemblage and single *Cochliopina* are synchronous, with the single *Pygophorus* following an opposite trend. From 40cm upwards single *Pygophorus* and *Cochliopina* are synchronous and the mixed *Pygophorus* assemblage shows an opposite trend. The most interesting point is that the mixed *Pygophorus* assemblage and the single *Pygophorus* specimens do not show the same record suggesting the mixed assemblage maybe from individuals that are not exactly the same age and thus the record is an average over a wider time scale. The records from the gastropods are much more variable than the bulk carbonates. This is a trend noted in other sequences.

The $\delta^{13}C$ record shows stability from the base to 55cm, values then continue to be stable but are much more negative. From 30cm to 15cm there is a prolonged positive trend which is reversed to the top of the record. This record is echoed by the *Pygophorus* sp record (Figure 8.14).

Magnetic susceptibility has also been measured for this sequence (Figure 8.15). The values are all negative apart from at the base of the sequence. This record should be treated with caution because it is likely these measurements are at the limits of the sensor's capability due to the number of points that have the same value. C:N ratios were measured on this core and the record falls into two distinct phases from the base of the record until 36cm where values are stable around 33; there is then a

transitional phase where values drop and then from 26 to 5cm values are stable at 16 rising to 19.5 at the top of the record (Figure 8.15).

8.5.1 Preliminary Analysis:

Both the $\delta^{13}C$ and the C:N record show a change in state from 35cm onwards suggesting there has been a change in the source of organic matter reaching the system. This same reciprocal relationship is seen in L1.

The distinctive part of the L1 and the L4 records is the banding of the sediments. This banding is only apparent between 12-30cm in the Honey Camp 2000 record. The rest of the sequence is uniform grey sediment. This has two implications:

1. If there has been a break in sedimentation in L1 and L4 it affected the whole lagoon as the three cores all show approximately the same amount of banded sediment.
2. The oxygen and carbon isotopic signature for 12-30cm in Honey Camp 2000 is akin to L1, L4 and Honey Camp 1999 for the equivalent depths which is evidence that the cores may be recording the same events.

The record from Honey Camp 1999 undergoes a large isotopic shift at 70cm. This is not apparent in the Honey Camp 2000 record at the same depth. Through looking at the relationship between L1 and L4 it is apparent that although sequences may cover the same time period, the recording of the events may not be the same. The base of the Honey Camp 2000 $\delta^{18}O$ sequence is the most negative for the whole sequence implying this period is a time of change even though the signal is not as large. This is not unexpected as the Honey Camp 2000 sequence was taken from 4 metres of water and therefore it may be less sensitive to change than the shore record.

The dry period apparent in L1 and L4 is not picked up in the Honey Camp 2000 record but this is more likely to be a result of sampling resolution. The C:N record also does not register change through this period. A positive excursion does occur at

40cm. This is where the shift to dry conditions is completed by in Honey Camp 1999 and dates to 565 ^{14}C years BP (after hardwater correction).

The two Livingstone cores taken in Honey Camp Lagoon (L4 and L1) are very short. In both instances the corer was unable to penetrate the sediment any deeper. Several other cores were also taken from the lagoon and these were of a similar length which suggests there is a lagoon wide sedimentary layer which is much denser than the sediments above it. The cores do not however record this, as the corers did not penetrate the layer.

It is important to try and work out how Honey Camp Lagoon 1999, L1 and L4 match. The links can only be regarded as preliminary due to the poor dating control on the cores. The transition to positive δ^{18}O values begins at 55cm (1251 years BP) and is complete by 40cm (565 ^{14}C years BP). The peak in positive conditions in L1 and L4 at around 15-17cm can only be said to occur at some point after 764 ^{14}C years BP. The hypothesis is that this peak in L1/L4 coincides with this transitional zone in Honey Camp Lagoon 1999. The idea was postulated that the L1/L4 have been affected by a break in sedimentation because the date for 19cm of 3315 ^{14}C years BP is extremely old for such a short depth. The equivalent time period is equal to 77cm in the Honey Camp Lagoon 1999 record. One idea is that the break in sedimentation occurred after the peak in the isotopic signature in L1 and L4. The break in sedimentation therefore encompasses the large negative shift in the δ^{18}O record at 1894 years BP. This suggests this was a very significant event and may be part of the reason behind the postulated break in sedimentation.

8.6 Summary of Honey Camp Lagoon

The key difficulty in interpreting the records from Honey Camp Lagoon is the lack of a reliable chronology within which to place the changes. The dates that are quoted should therefore be regarded as preliminary. The following summary points can be made:

1. It is postulated that the Honey Camp Lagoon 1999 sequences covers the entire Holocene period. The transition to the Holocene in the Hillbank 1998 record is marked by the most positive $\delta^{18}O$ values for the entire sequence. The values for the same time period are more positive in Honey Camp, but they are not the most positive in the whole sequence (10900-8300 years BP). Further dates are needed to clarify that the record does indeed cover this time period.
2. The main part of the Honey Camp 1999 $\delta^{18}O$ record is stable (8300-2100 years BP). The values shown are akin to those in the New River Lagoon.
3. The $\delta^{13}C$ results in the same period are however very different suggesting the carbon systems for the two lagoons are driven by different causal mechanisms.
4. The first half of the Honey Camp Lagoon 1999 record (up to c. 4500 years BP) shows highly variable mean particle size and C:N ratios which is evidence the system is being influenced by the catchment rather than just within-lagoon processes. This is more confirmation that Honey Camp Lagoon in this time period was more similar to the New River Lagoon than it is at present.
5. The key period of change in both the $\delta^{18}O$ and the $\delta^{13}C$ record in Honey Camp Lagoon 1999 is at 70cm (c. 1900 years BP) which is marked in both as a large negative excursion. The causal mechanisms behind this are likely to include a change in the catchment vegetation, an increase in the oxidation of organic matter and high rates of flushing through the system all within a much moister climate.
6. It is postulated that L1 and L4 have been affected by a break in sedimentation which is likely to have occurred at the time of the large negative shift in the $\delta^{18}O$ record from Honey Camp Lagoon 1999. This is further evidence this was a very significant time period in the lagoon's history.
7. There is a second negative peak in the $\delta^{13}C$ record at 55cm (c. 1200 years BP). This is also where the transition to the most positive $\delta^{18}O$ values in the sequence begins.
8. The levels of both $\delta^{18}O$ and $\delta^{13}C$ are very much enhanced in the top 40cm of the record. This is the only zone where gastropods are preserved. L1, L4 and Honey Camp 2000 all have similar isotopic values through this period.

9. L1 shows clear evidence that this part of the lagoon has operated as a closed system throughout the time period covered by the core. The difference between L1 and L4 highlights the importance of core location in the dissemination of trends.
10. The key point of change in the L1 and L4 record is a positive excursion in both the $\delta^{18}O$ and $\delta^{13}C$ records at some point before 764 ^{14}C years BP. The coherence of both cores and proxies suggests this was a severe event and therefore could be related to the late Holocene dry period.
11. The human occupation history of Honey Camp Lagoon occurred in two phases. It is possible that the interruption was the late Holocene dry period and therefore the Mayan people in this area may have been influenced by the climate to a greater extent than the population at Lamanai.

Honey Camp Lagoon

Basemap: DOS Sheet 5 Edition 3-GSGS (1994), Scale 1:50,000
Projection: Universal Transverse Mercator (Zone 16)

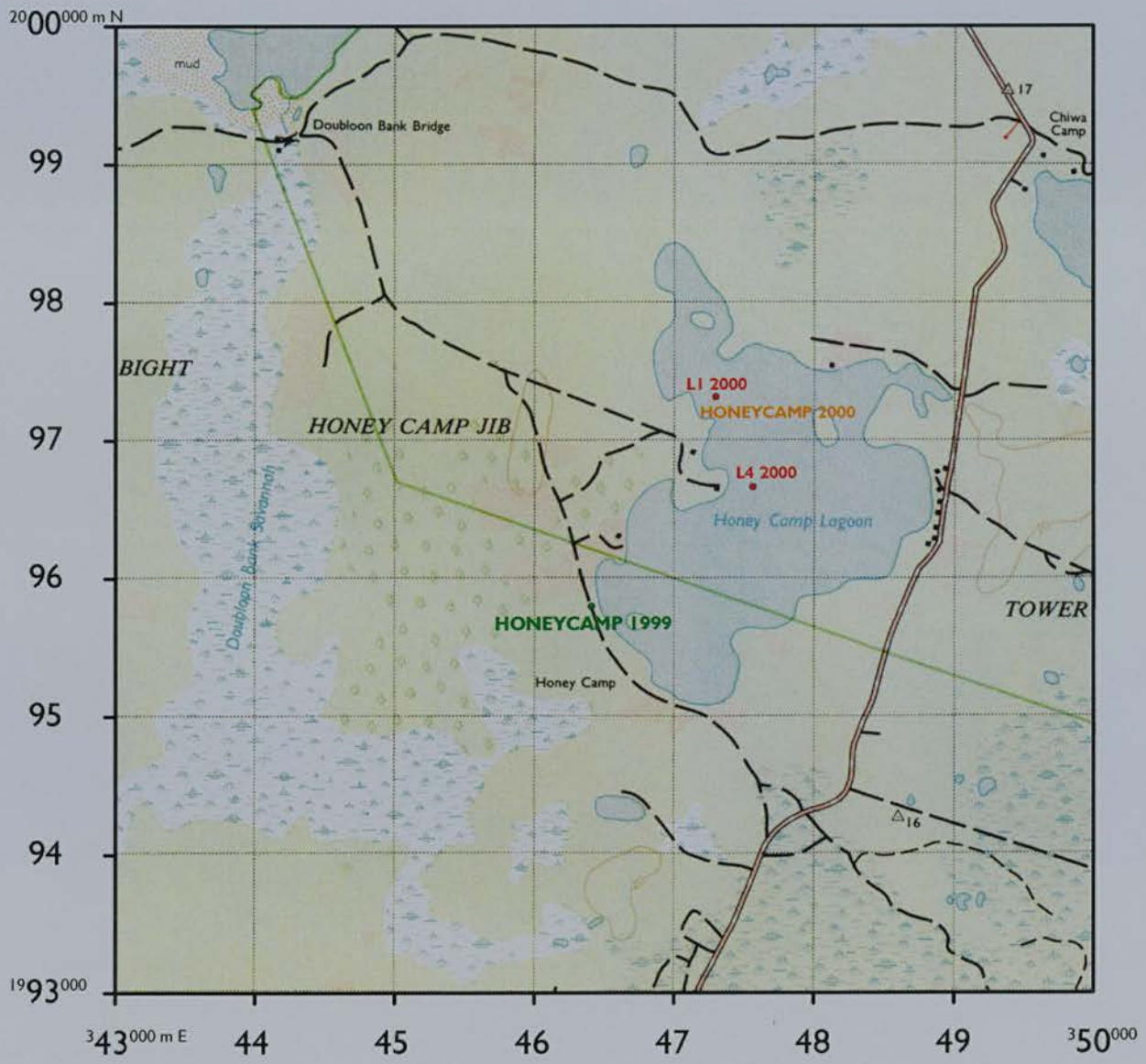


Figure 8.1
Modified from Murray (unpub.)

Figure 8.2 Honey Camp Lagoon

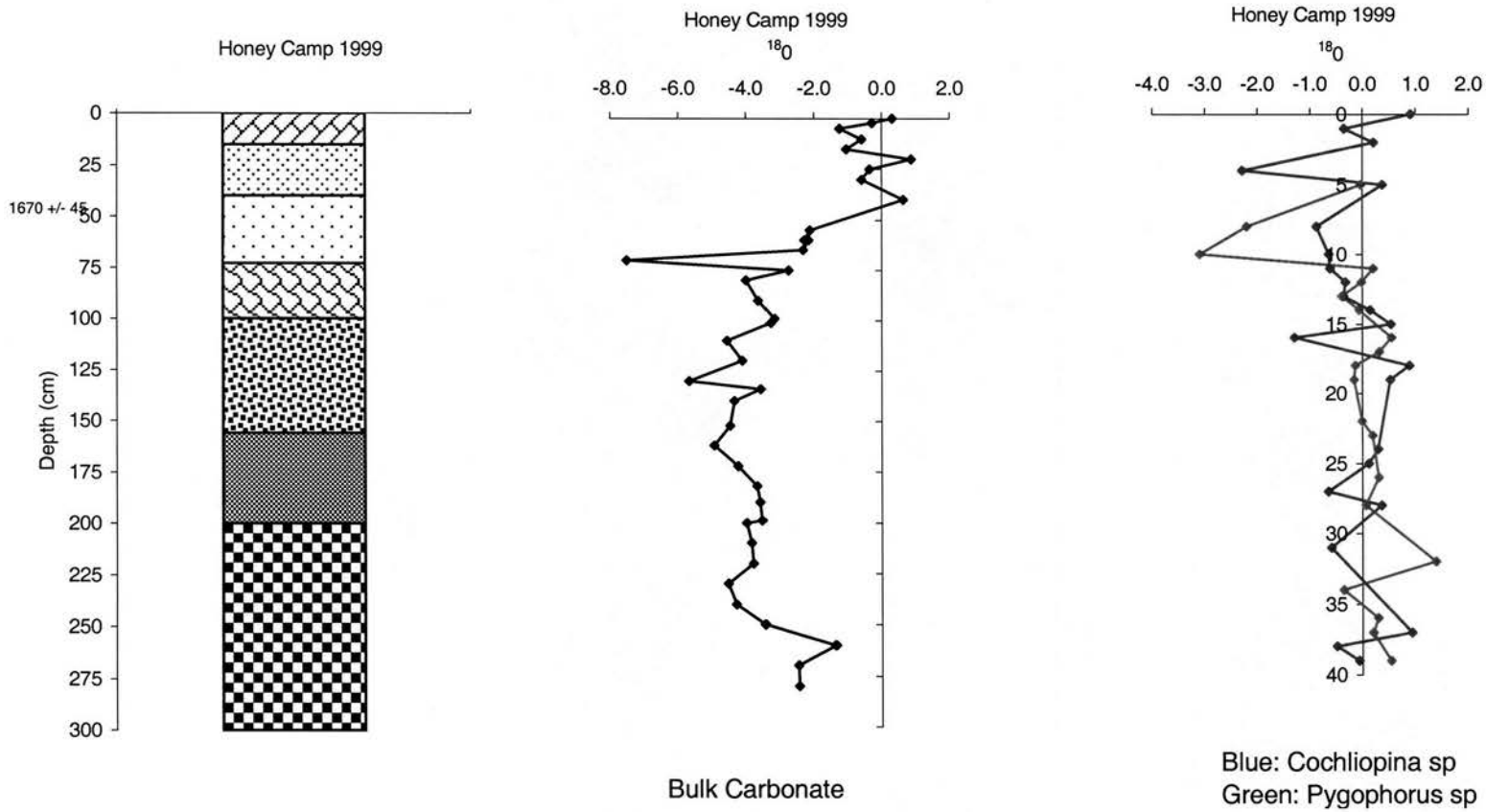


Figure 8.3 Honey Camp Lagoon ^{18}O records (Note change of scale in gastropod record)

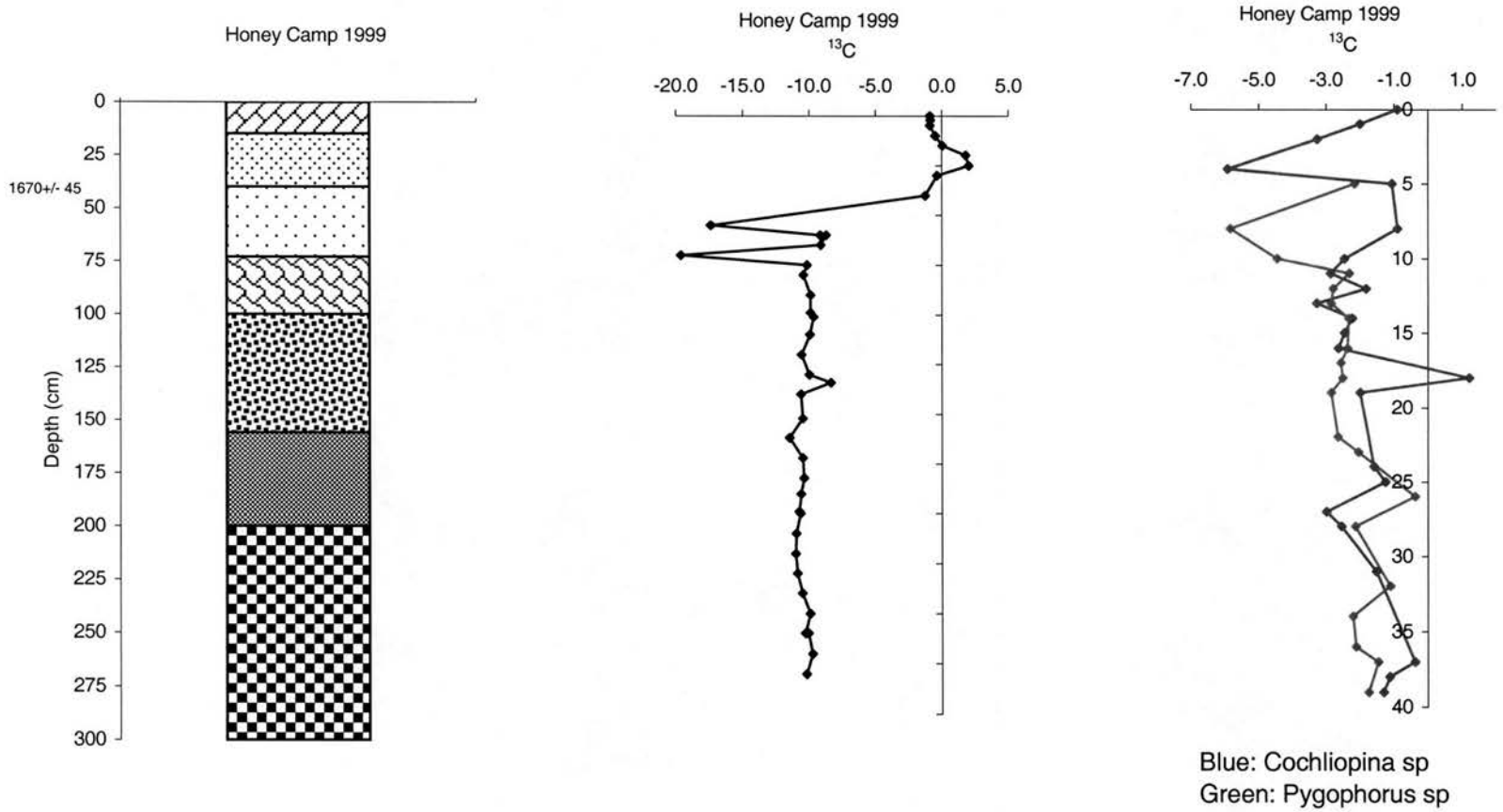


Figure 8.4 Honey Camp Lagoon ^{13}C records (Note change in scale on gastropod record)

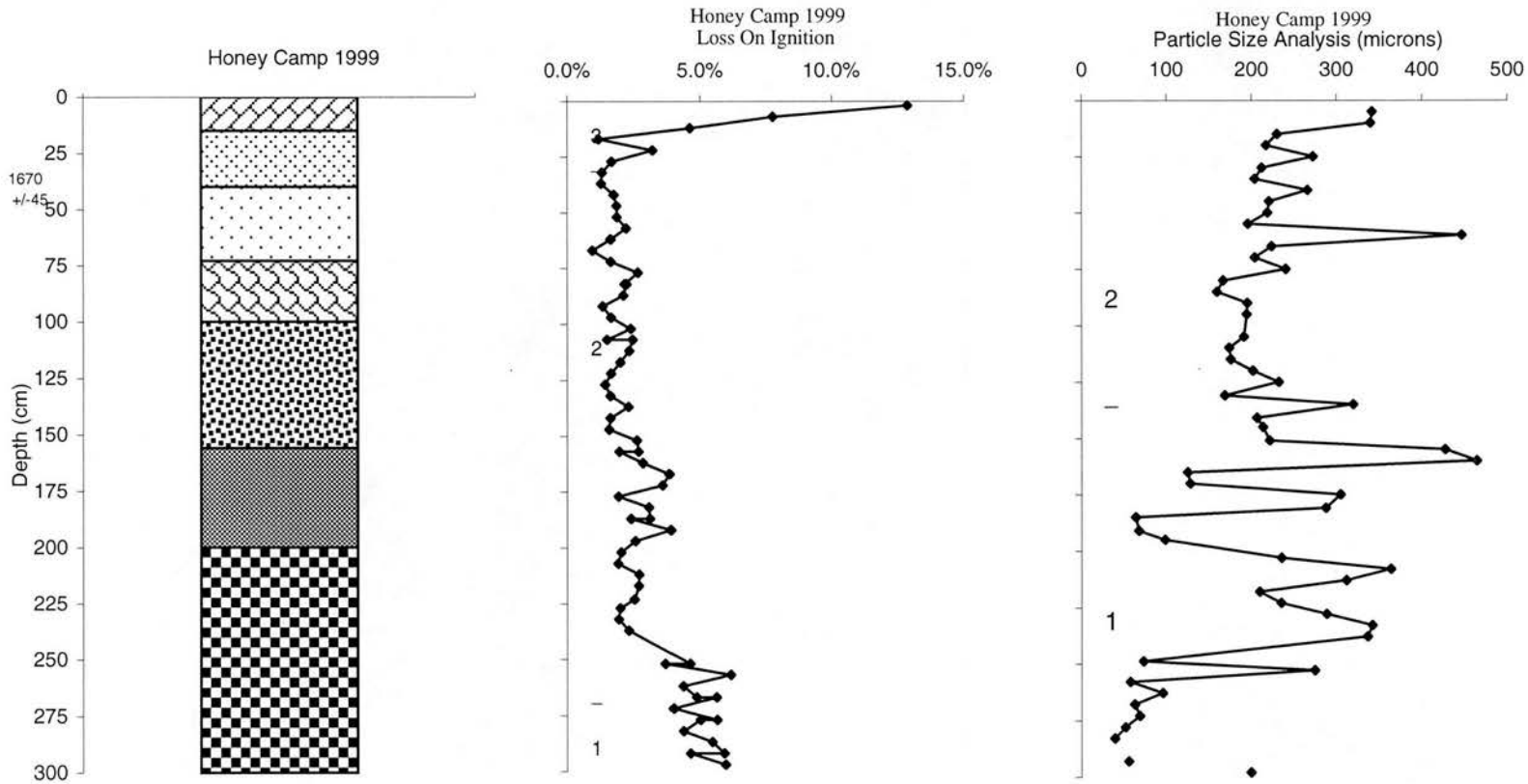
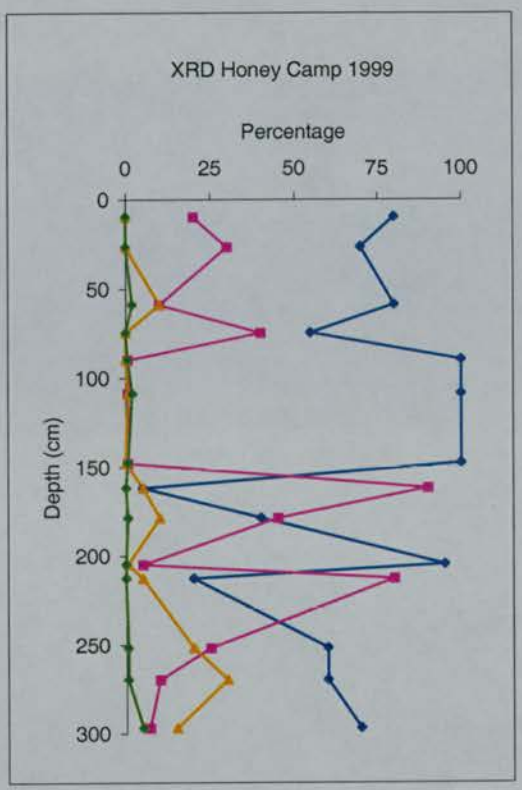


Figure 8.5 Honey Camp Lagoon Loss on Ignition and Particle Size Analysis

Figure 8.6



Key:
Quartz: Blue
Calcite: Pink
Smectite: Orange
Green: Kaolinite

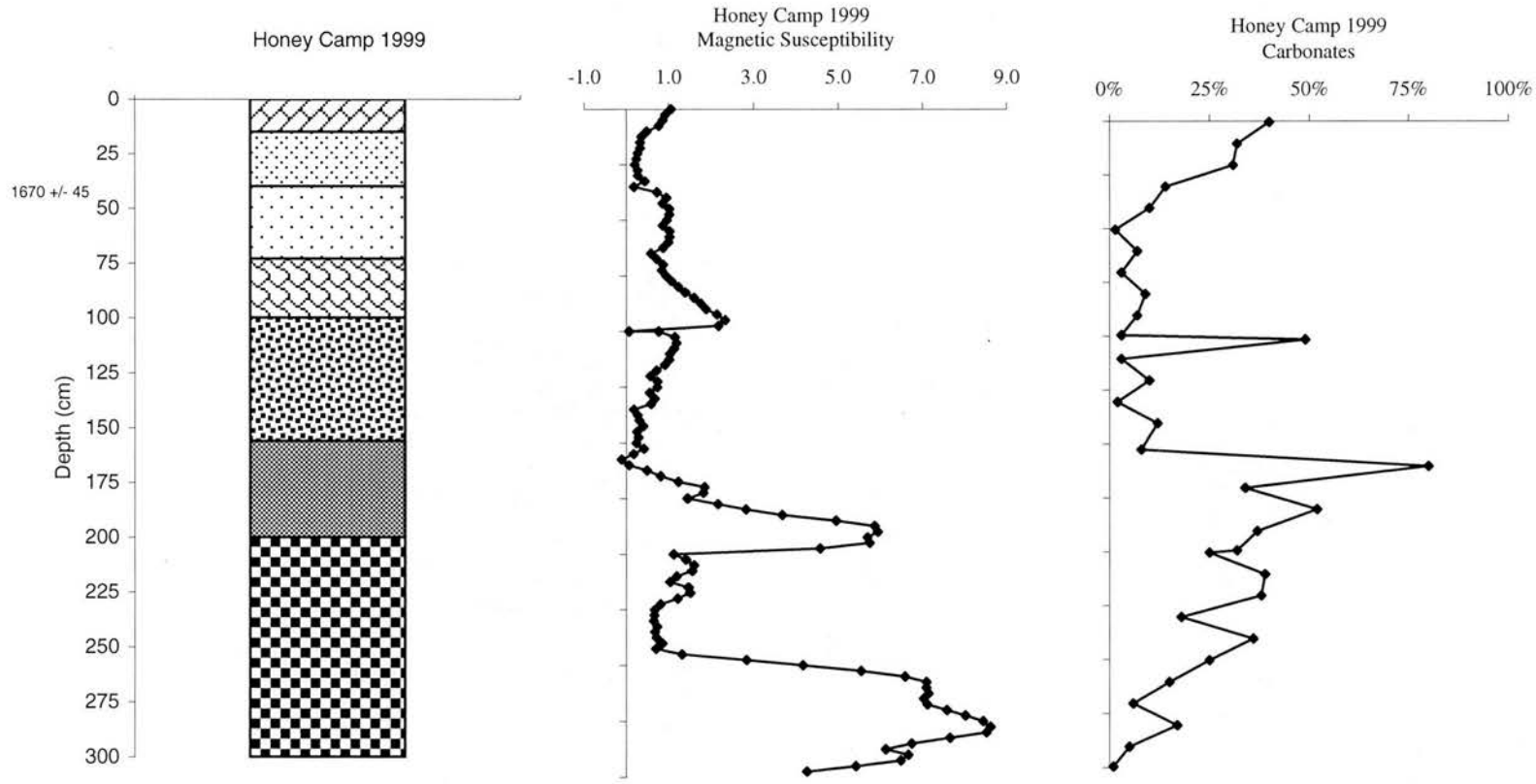


Figure 8.7 Honey Camp 1999 Magnetic Susceptibility and Percentage Carbonates

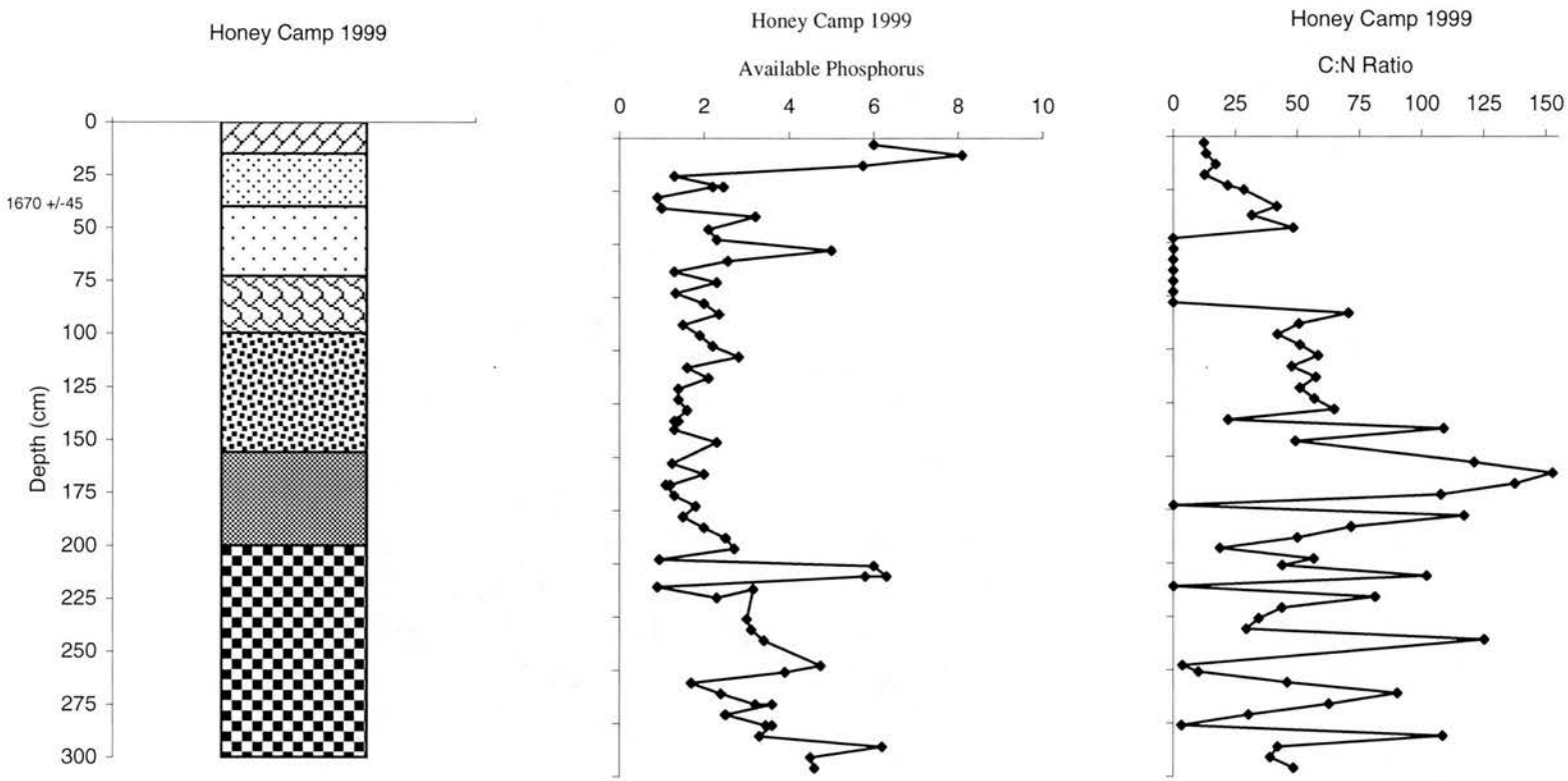


Figure 8.8 Avaliable Phosphorus and C:N Ratio in Honey Camp Lagoon 1999

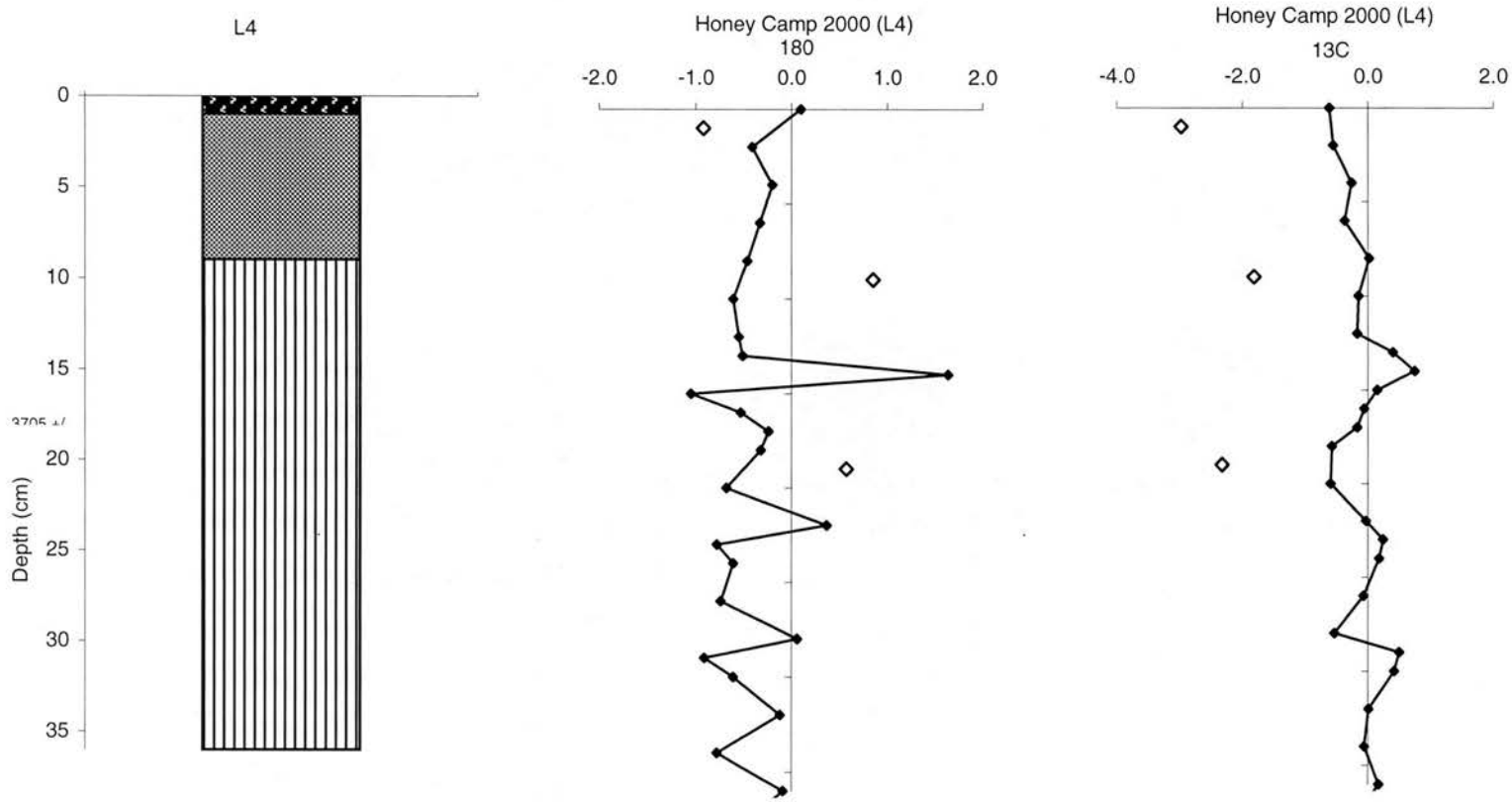


Figure 8.9 Honey Camp L4 Stable Isotope results

Open diamonds: Pygophorus sp

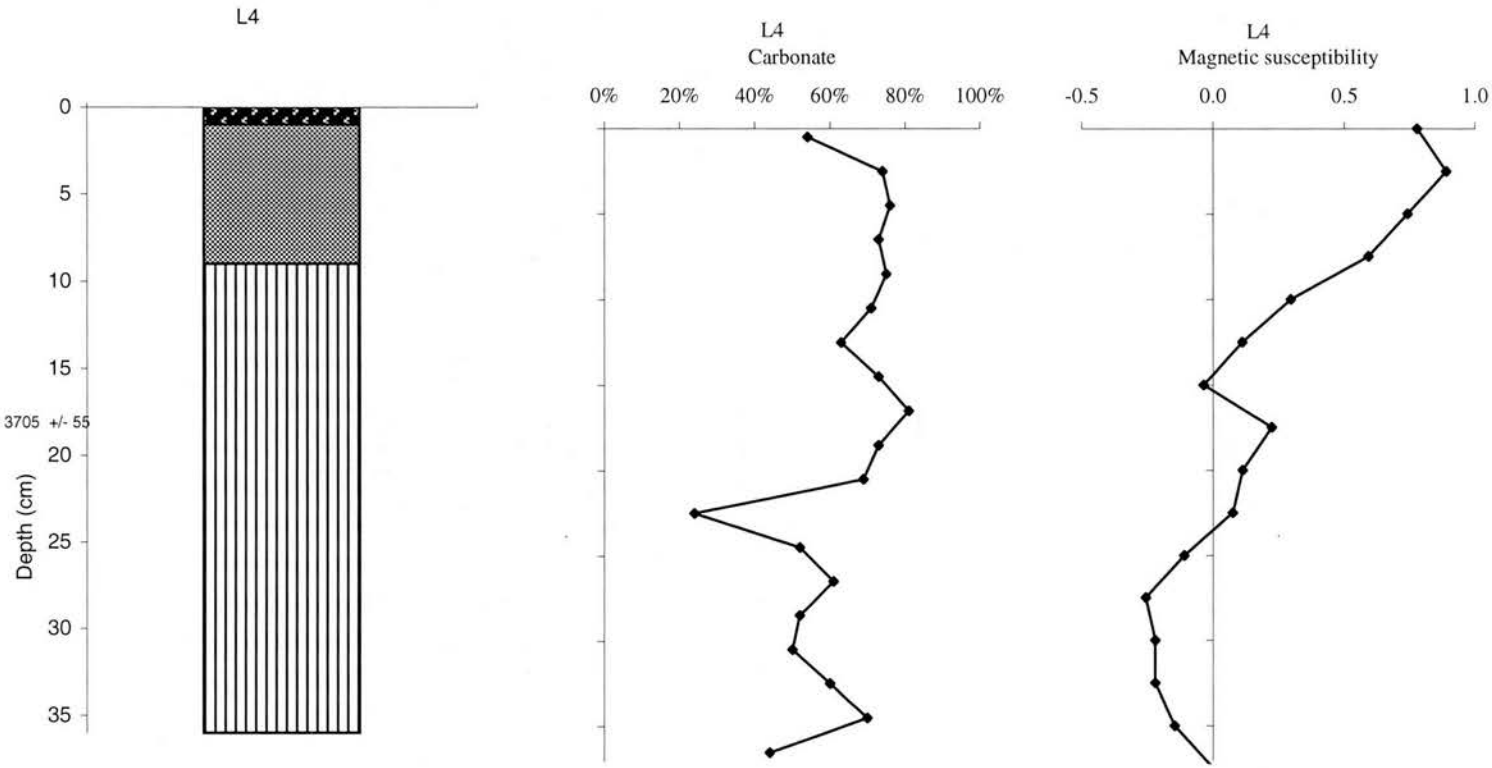


Figure 8.10 Honey Camp L4 Carbonate and Magnetic Susceptibility Results

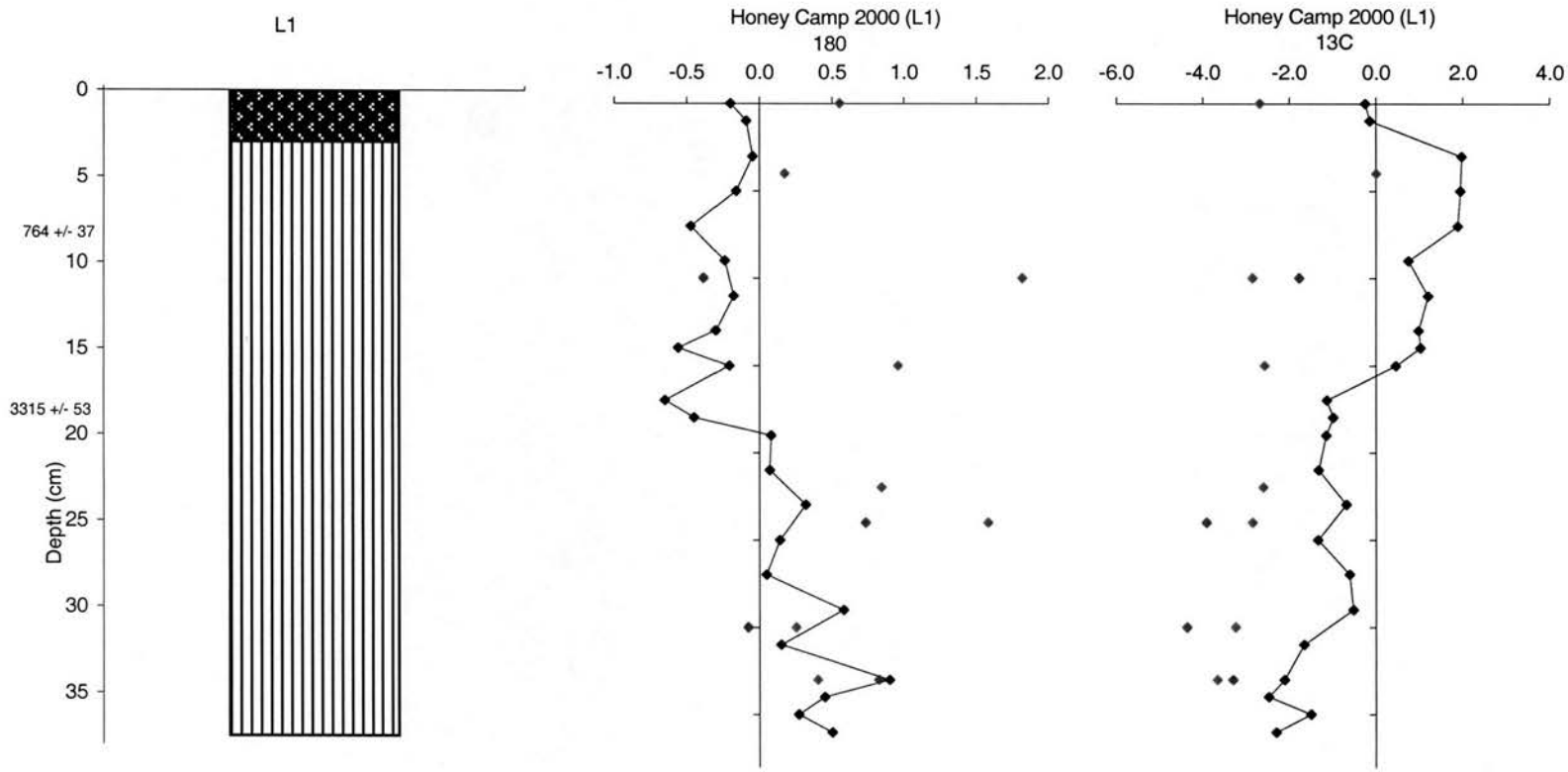


Figure 8.11 Honey Camp L1 Stable Isotope Results

Blue: Cochliopins sp
Green: Pygophorus sp

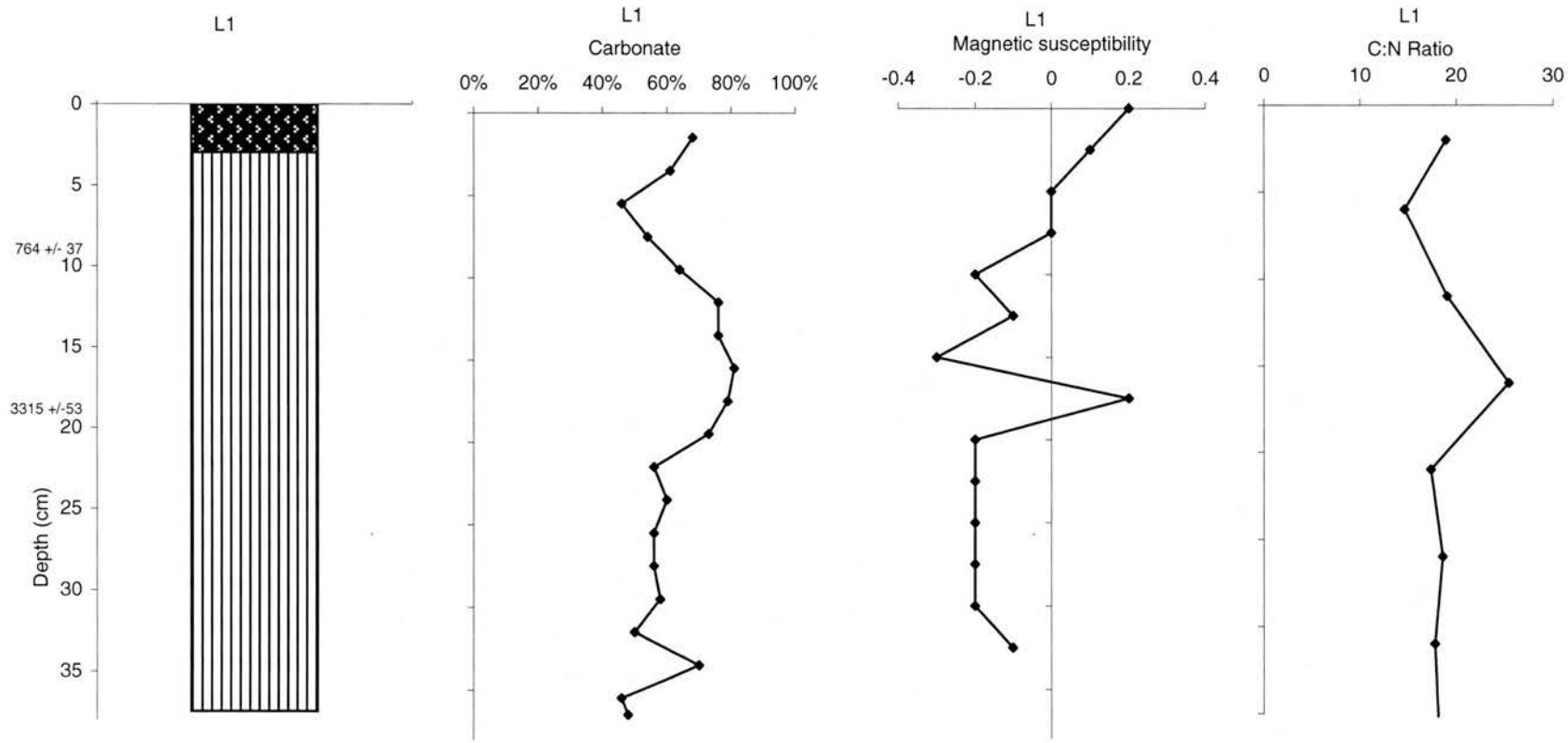


Figure 8.12 Honey Camp L1 carbonate, magnetic susceptibility and C:N ratio results

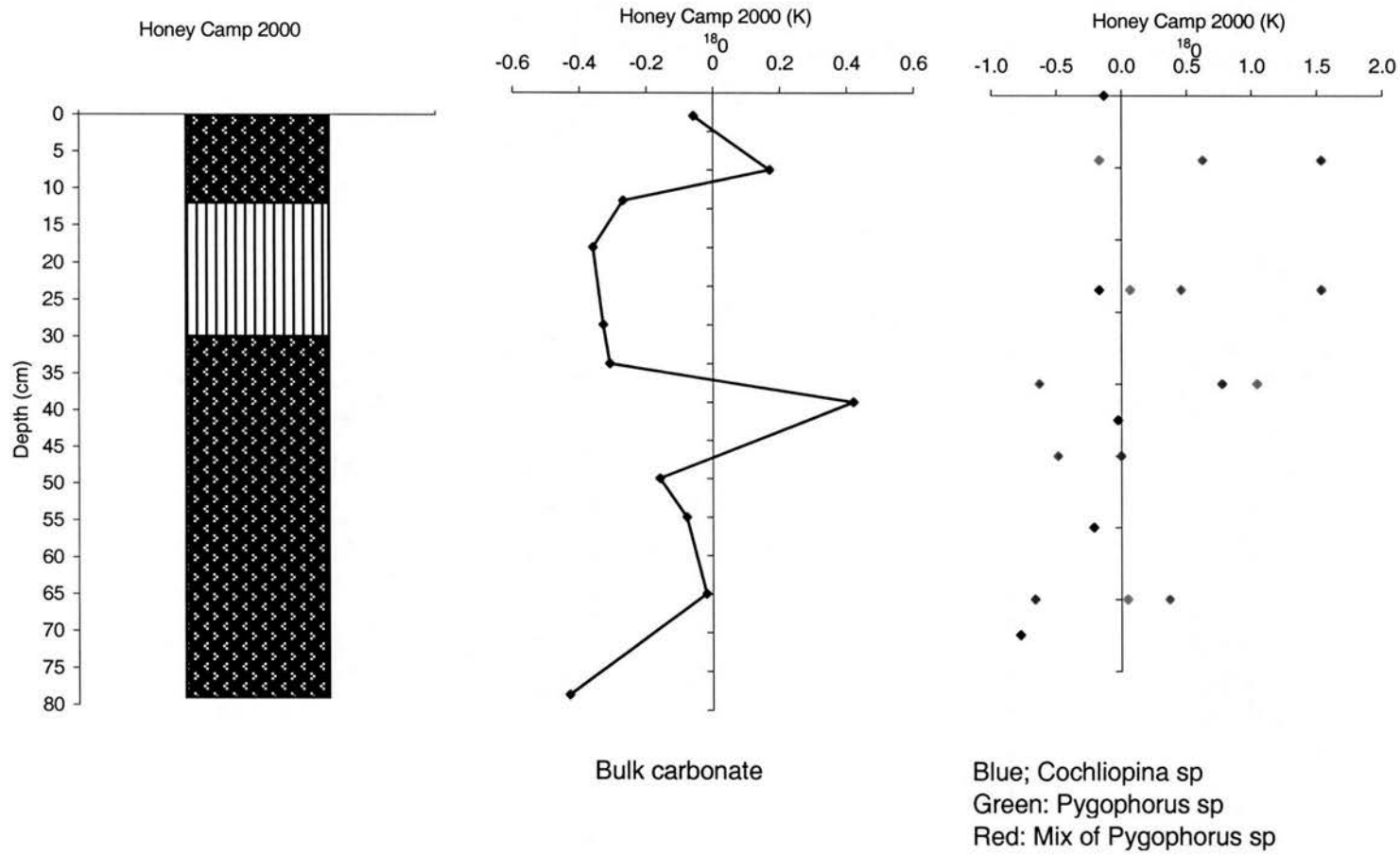


Figure 8.13 Honey Camp 2000 stable isotope results

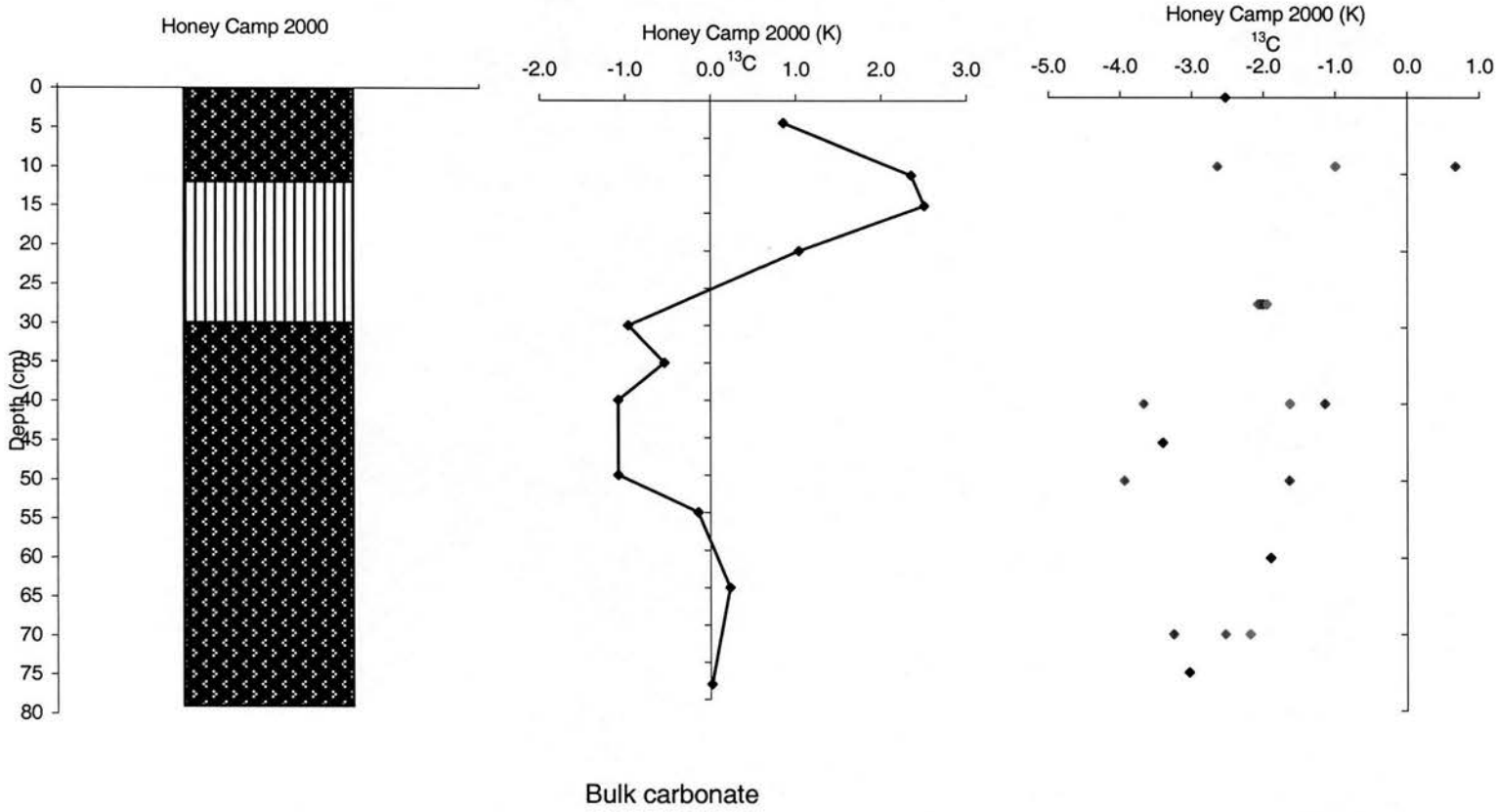


Figure 8.14 Honey Camp 2000 Stable isotope results

Blue; Cochliopina sp
Green: Pygophorus sp
Red: Mix of Pygophorus sp

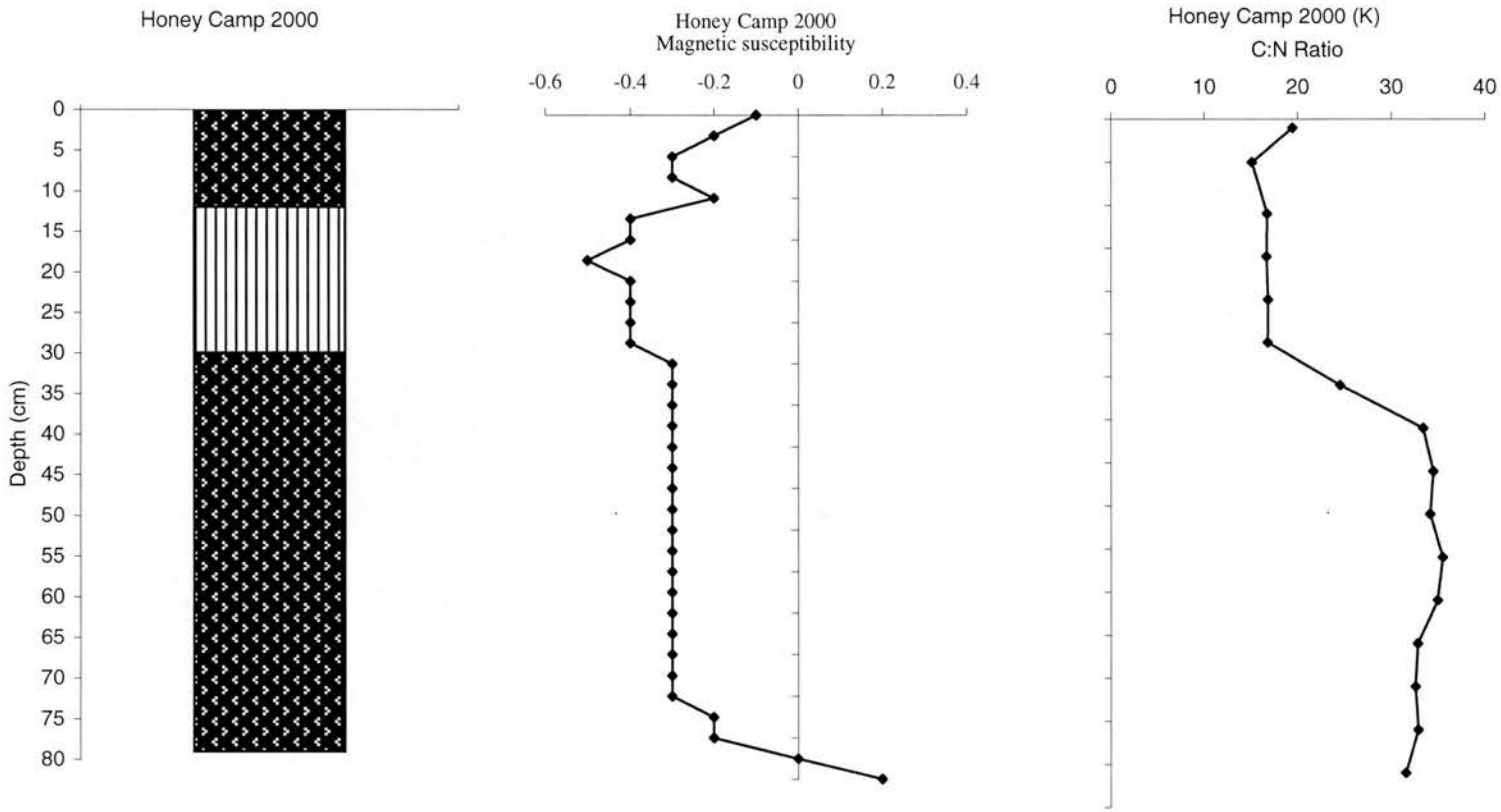


Figure 8.15 Honey Camp 2000 Magnetic susceptibility and C:N ratios.

Chapter Nine: Discussion and Conclusions

This chapter aims to bring together the results of this thesis from both the modern and the past environments of Belize and sets the findings within the context of regional changes.

9.1 The modern environment

From the modern limnological studies it is apparent that the lakes studied in Belize fall along a geochemical gradient from calcium-bicarbonate (freshwater) to calcium-sulphate to sodium-chloride dominated systems. Diatom preservation was not good in the latter group following the pattern set out by Flower (1993). In terms of the fossil diatom records, preservation was changeable in the New River Lagoon (calcium-sulphate dominated) and very poor in Honey Camp Lagoon (sodium-sulphate-chloride dominated). In order to ensure that diatoms are preserved through the sequence, cores from the freshwater sites could be taken (i.e. from Kates Lagoon, Crooked Tree Lagoon and Chiwa Lagoon (Figure 4.1). Access to the latter two sites is difficult. Silica availability is a key variable important in diatom preservation. This would also need to be monitored to determine whether silica availability is a limiting factor for diatoms in Belize. Results from this would also aid site selection for future diatom work.

The characterisation of the water bodies visited was not sufficient to enable transfer functions for Belizian diatoms to be created. This must be regarded as a priority for future research in order to enable quantitative diatom species ecology in Belize. Such information is particularly pertinent with regard to the ecological relationship between different geographical areas. It has become apparent in the samples investigated, that habitat is one of the important factors controlling distribution of the diatom species. This may, however, be a function of the sampling strategy employed. Further water chemistry analysis would enable an improved understanding of the role of this variable in controlling species distribution. One way in which

water chemistry data could be more intimately connected to the diatom samples would be through the collection of water chemistry variables in the weeks running up to the collection of the diatom sample. These data would then provide an indication of the range of conditions to which the species are adapted.

Studies in the modern environment are essential to the understanding of the forcing factors behind change. The role of habitat in the evolution of two varieties of *Mastogloia smithii* var. *lacustris* could not have been determined without such a study. This is especially important as both of these varieties are present in the fossil record. The environmental reconstruction from the core Lamanai 1999 is much more tightly constrained as a result. The study of *Mastogloia smithii* var. *lacustris* also highlighted the point that species found in the tropics may not fall neatly into the categories assigned to European species. There is the potential for a great deal more taxonomic work in Belize with samples currently only taken from a limited number of habitats at one time of the year. To enable the true characterisation of the water bodies and their diatom populations in Belize, samples would have to be taken throughout the year and with an increased sampling density in lakes so that more detailed ecological information can be gained.

9.2 The past environment

From the work that was carried out at Hillbank, New River Lagoon it is apparent that the climate of the late Pleistocene was very variable. Despite the large variations through time in the stable isotope records, the diatom species present in this period are uniform throughout. This suggests that the climatic changes occurring did not influence the factors controlling diatom distribution during this time. It could therefore be presumed that because habitat is an important forcing factor in the present day, it was also important in the past. The transition to the Holocene is marked by very poor diatom preservation and the driest conditions in the entire Hillbank record. This represents a clear shift in climatic conditions and, with improved dating control, this may in fact prove to be a Younger Dryas signal. Drier

conditions are also postulated to have occurred at this time at Honey Camp Lagoon. These are not as severe as those in Hillbank, but again improved dating control is needed to verify the exact timing of these changes.

For the main period of the Holocene, the records from Hillbank and Honey Camp show stable and moist conditions. The next key period of change begins at c. 4922 years BP in Hillbank. Around this time the isotopic signal and diatom preservation become much more variable. There is also an increase in disturbance pollen. The coincidence of all these factors suggests that this represents the beginning of a new period in Belizean history. It could be suggested that these factors are related, with climatic changes occurring at the same time as the first potential signs of human activity in the area.

The shift to late Holocene dry conditions was gradual with the amount of pine pollen in the Hillbank catchment increasing from c. 4800 years BP. From c. 4500 years BP a new phase also begins in Honey Camp Lagoon. At this time the lagoon shifts from being dominated by catchment processes to within lagoon processes. All the evidence suggests that this is an important period of environmental change in this area. This may represent the point at which Honey Camp lagoon shifted from being an open to a closed system. The driving force behind this change could be climatic such as a shift to drier conditions. The oxygen isotopes in Hillbank show a drying trend from c.3000 years BP. At this time there is a significant increase in reconstructed conductivity values from the diatoms at Hillbank. It is also during this period that the Lamanai 1999 record begins. The isotopic values in Lamanai and Hillbank around 3000 years BP are very similar, suggesting that they are recording similar conditions.

The Lamanai sequence records clear episodes of change which could be related to human activity in the catchment. These are represented by three main shifts in the carbon isotope record. These coincide with periods of building activity, as deduced from archaeological evidence. These events approximately date to:

1. 2180 years BP (196 BC). This is during the period when temple N10-43 was being built. This is the tallest building in Lamanai and would have required a considerable workforce plus associated societal hierarchies to organise the site at this time.
2. 1820 years BP (AD 277). This coincides with the building of P9-2 and P8-12. These are located north of N10-43. P8-12 is located next to a harbour.
3. 1240-870 years BP (AD 782-1192). The peak in the carbon isotope record through this period is not as high as in the past but it is much more prolonged (c.300-400 years cf. c. 570 years). This coincides with the considerable modification of a group of buildings known as the Ottawa Complex. This group is located at the south end of the site. The Lamanai 1999 core was taken parallel to the Ottawa Complex which may account for the prolonged signature in the isotope record.

The apparent consistency of the archaeological and sediment records is very encouraging because it clearly demonstrates the impact of humans on the environment. The creation of a pollen record in this area would be beneficial, providing evidence for changes to the amount and type of vegetation in the catchment. Such information is essential to prove the connection between carbon isotope fluctuations and human activity. Evidence from archaeologists relating to population estimates would be invaluable in order to develop a better understanding of human dynamics in this area.

Around 1900 years BP there is a large negative shift in the oxygen isotope record from Honey Camp. Significantly, the system does not return to its original condition after the change. The two short cores from this lagoon (L1 and L4) are thought to have a break in sedimentation in their sequences during this time period. This sharp change in sedimentation rate may have been a response to the significant environmental changes that were affecting the system at this time.

Of particular note is the fact that the modification of the Ottawa Complex in Lamanai occurred during the period commonly referred to as the 'collapse' of the Mayan Civilisation. Clear evidence of disturbance in this period is proof that a society in Lamanai existed throughout this time. Although this was not a building phase, 20,000 tonnes of stone are estimated to have been moved as part of this process (Graham, 2001). This therefore represents significant manpower and organisation in the Mayan society. What is apparent is the changing priorities of the society during this time. This may have been a response to the difficulties that nearby sites were experiencing.

The core Outpost 2000 was taken 1.5 km south of Lamanai 1999 and could be suggested that the human impact signature at this site may not be as pronounced. During the 'collapse', the carbon isotope record in Outpost 2000 shows a period of catchment recovery centred around c. 1100 years BP (AD 970). This highlights an important methodological point. This time period has been covered by two records which both represent different sequences of events. This demonstrates that it is important to obtain a good geographical spread of coring locations in order to ensure that the events can be correctly understood.

The collapse of the Mayan Civilisation has been attributed to the late Holocene dry period (e.g. Curtis *et al.*, 1996). This period is identified in Lamanai by a significant change in the diatom flora. Diatoms are influenced by a number of different factors and therefore it is likely that this change could be related to catchment disturbance resulting from building modification of the Ottawa Complex at Lamanai during this time. The $\delta^{18}O$ record in Lamanai is remarkably stable from 1240-870 years BP. This is unusual in the context of the record and therefore is significant. In cores L1 and L4 from Honey Camp Lagoon there is a distinct positive excursion in the $\delta^{18}O$ records that occurred at some point before 764 ^{14}C years BP (AD 1265). It can therefore be postulated that this change is related to the late Holocene dry period. There is also clear evidence from Honey Camp for a drying trend from 1200 years BP onwards. The records from Hillbank do not cover this time period.

From the results gained in this study it is difficult to judge the severity of late Holocene dry period. The shift to dry conditions is very pronounced in the Honey Camp 1999 record, but it is not a discrete episode and dry conditions are maintained to the top of the sequence. The shift in L1 and L4 is, however, a distinct event. This difference is likely to be a result of the higher resolution of the latter records.

Both the Outpost 2000 and the Hillbank 2000 records show evidence for colonial activity in their catchments. The archaeological site of Lamanai was abandoned in AD 1640 and from this point the Outpost sequence shows signs of preliminary catchment recovery. From AD 1862-1917 a sugar mill was operating in this area and this period is clearly one of disturbance in the catchment. In a similar manner Hillbank 2000 records disturbance between AD 1897-1917. This is most likely to be due to the colonial logging that was prevalent in this area. The New River Lagoon was a principal site for the logwood industry in Belize. Logwood exports reached a peak in 1895 at 35,500 tons which equates to the beginning of disturbance in the sediment sequences. By 1920 exports had dropped to 1,500 tons primarily due to the development of synthetic dyes (Duncan, 1966). This demonstrates that the colonial settlers also had an impact on the environment.

9.3 The records from Belize

Although limited (see Chapter 2), there is information available concerning the environmental history of Belize. In Cobweb Swamp there is evidence for sea level rise between 5600-4800 ^{14}C years BP. Laguna de Cocos, Albion Island also records mesohaline conditions during this period. This is not however a period of enhanced reconstructed conductivity in the Hillbank 1998 diatom record. Throughout the whole record the diatoms in Hillbank record oligohaline conditions. Further research is therefore needed to determine the nature and extent to which sea level rise affected Belize away from the immediate coastal zone.

Zea mays is found in Cobweb Swamp and Albion Island between 3000-3500 ^{14}C years BP and is an indicator of early agriculture. *Zea mays* was not picked up in the Hillbank pollen record. This does not necessarily suggest that it was absent in this area of Belize, owing to the low resolution of the Hillbank sequence. The evidence for the possible impact of humans in Hillbank occurs at c. 5000 years BP with a peak in *Chenopodiaceae* pollen - from herbs that grow in response to agricultural disturbance. This matches with the pollen evidence from Laguna de Cocos, Albion Island where human activity is indicated by *Zea mays* (Hansen, 1990).

There are two studies which have drawn conclusions on the palaeoclimate of Belize. Bradbury *et al.* (1990) found evidence for a drier climate 5-6000 years BP. In order to substantiate this, more evidence on the patterns of change in the Rio Hondo (the river in which Albion Island lies) is required. The climate is then believed to have become increasingly moist in the period beginning around 5000 years BP. At this time Laguna de Cocos moved from being sodium chloride dominated to a freshwater system. There is no evidence from the records gathered in the present study for a drier climate from 6000 years BP. Between c. 5500-5400 years BP there is a shift to moister conditions in the Hillbank record. However, this is not a sustained excursion. The New River Lagoon is part of the same system as to the New River, which eventually links to the sea. Due to the proximity of the New River to the Rio Hondo (Figure 1.1) it would be expected that both would be affected by the same external events and respond in a similar manner. Hillbank is located a considerable distance away from the New River which means that the magnitude and extent of any change to this system will be less than in areas such as Albion Island. This perhaps accounts for the drying signal noted at Albion Island c. 6000 years BP and yet not at Hillbank.

A further increase in moisture is seen in the Albion Island record from 1700-1600 years BP. It is hypothesised that the negative excursion in the Honey Camp Lagoon 1999 record at c. 1900 years BP could be the manifestation of this event. From AD 1000 Bradbury *et al.* (1990) note a drying trend on Albion Island. This is likely to be the late Holocene dry period signal detected at Honey Camp and Lamanai.

Despite northern Belize being a small area, it is apparent that there is variation in the environmental histories that have been produced, reflecting the influence which the local environment has on how a signal of change is recorded. This observation highlights the importance of not only a multiple coring strategy, but also a region-wide strategy so that a better grasp of the area's dynamics can be gathered. This needs to be coupled with an understanding of the present day interconnections between areas, so that differences between sites through time can be explained. The importance of high-resolution records is also key so that the magnitude and severity of events can be more faithfully assessed.

9.4 The wider picture

In order to place the records from Belize within a meaningful context, the results gained in this study need to be compared with those already produced for the circum-Caribbean. These records are described in Chapter 2. A summary of the results found in Belize is shown in Figure 9.1. Figure 9.2 highlights the links between Belize, Guatemala and Haiti.

The record from Hillbank shows evidence for climatic drying in the period immediately prior to the Holocene. It is postulated that this is a Younger Dryas signal. The climatic signal for this period in the Tropics is geographically specific. At this time Lake Miragoane, Haiti has a clear drying signal (Hodell *et al.*, 1991). This is different from nearby Guatemala and Costa Rica which show a cool, moist signal (Deevey *et al.*, 1983; Leyden, 1984; Hooghiemstra *et al.*, 1992; Leyden *et al.*, 1993; 1994; Brenner, 1994; Islebe *et al.*, 1995). These results suggest that during this period the climate of Belize was most similar to the climate of the Caribbean. This is probably because of the particular ocean-atmosphere interactions driving climatic change at this time. These causal mechanisms account for the signal seen in Guatemala and Costa Rica – increased seasonality, decreased SSTs and rising sea level – resulting in cool, wet conditions. How can the dry signal in Belize be

accounted for? Due to their geographical proximity all the records are likely to have been equally affected by the shifts in the ITCZ movement. The records from Belize and Haiti are located much closer to the Caribbean Sea than Lake Quexil, Guatemala and La Chonta Bog, Costa Rica and are therefore more likely to be affected by changes to the Caribbean Sea. One hypothesis is that lower SSTs will decrease the amount of evaporation over the sea, therefore leading to a drier climate in coastal regions such as Belize and Haiti.

The transition to full moist conditions was completed at Hillbank by c. 8900 years BP which coincides with the rise in water level by 9000 ^{14}C years BP in Lake Peten-Itza (Curtis *et al.*, 1998). In general terms, there is a period of lake filling in Guatemala and the Yucatan Peninsula ranging from before 7230 ^{14}C years BP (San Jose Chulchaca, Yucatan Peninsula, Leyden *et al.*, 1996) to 9000 ^{14}C years BP (Lake Peten-Itza, Curtis *et al.*, 1998). This change has been attributed to increased moisture availability and sea level rise which enabled freshwater aquifers to rise (Fairbanks, 1989; Watts and Hansen, 1994). The oldest date in the Hillbank 1998 record is 9840 ^{14}C years BP and the system is lacustrine for the whole of the record (inferred from the presence of diatoms). This implies that the New River Lagoon has been a permanent water body for much longer than many of the lakes in the area. It therefore has great potential to produce an even longer record than analysed in this thesis. The longevity of the water body is likely to be a function of the low-lying nature of the lagoon which is presently surrounded by marshland and the faulted nature of the substrate geology.

The middle Holocene in Peten-Itza (6800-4800 ^{14}C years BP) and Lake Miragoane (7000-5300 years BP) is characterised by wetter conditions matching those in the Hillbank record. The wettest period of the Holocene in San Jose Chulchaca centred on 5085 ^{14}C years BP (Leyden *et al.*, 1996; Whitmore *et al.*, 1996). This is likely to be coincident with the increase in moisture seen at Hillbank between 5505-5381 years BP. After 5000 ^{14}C years BP there is a clear cultural signal in Guatemala, Honduras, Panama, Costa Rica and indeed Belize. The changes as a result of human

impact in the Yucatan Peninsula, Mexico are only found in much more recent times. In Peten-Itza this becomes more pronounced by 2800 ^{14}C years BP. However, this is not seen in the Hillbank pollen record. Records show a clear signal for the improvement of the forest ecosystem at around 1000 years BP in the Peten which is attributed to the collapse of the Mayan Civilisation.

Although the late Holocene dry period is thought to be wide in its extent (Hodell *et al.*, 1991; Horn and Sanford, 1992; Metcalfe *et al.*, 1994; Metcalfe, 1995; Hodell *et al.*, 1995; Curtis *et al.*, 1996), there is only one record in Guatemala from Lake Salpeten (Rosenmeier *et al.*, in press) that has preliminary evidence for climatic drying at this time. This period is not detected at all in Lake Peten-Itza (Curtis *et al.*, 1998). Curtis *et al.* believe that this is due to the large size of the lagoon which would render the sequence much less sensitive to fairly short-lived shifts in climate. This would also account for the limited signal in the New River Lagoon and the stronger signal in Honey Camp Lagoon, which is a closed basin. The Hillbank record does have evidence for drier conditions persisting from 3000 ^{14}C years BP which is similar to Lake Miragoane, Haiti where dry conditions began 3200-2400 ^{14}C years BP (Hodell *et al.*, 1991).

Clearly, the results of this study highlight the importance of geographical location when considering the signal of climatic change that is recorded. The times of dry climatic conditions in Belize occur at the same time as those in the Caribbean. However, when conditions are wet in Belize they coincide with those in Guatemala. This must be a function of the combination between the dominant forcing factors and how areas respond.

It is very difficult to judge the relative severity of the Lateglacial period and the late Holocene dry event. Due to lack of chronological control in the Honey Camp record it cannot be said with certainty that both events are found in the same sediment record. The Lateglacial period in Hillbank is represented by an extremely large isotopic shift which is much greater than any seen later in the sequence. The late

Holocene period in Honey Camp is also significantly drier than the rest of the record, but the episode is not discrete because these conditions are maintained until the present day. The two records which show this as a discrete event in Honey Camp have a much smaller isotopic shift than is seen in the Hillbank Lateglacial signal. The preliminary conclusion is therefore that for Belize the Lateglacial was drier than any episode recorded in the Holocene.

9.5 Methodology:

In this investigation three types of corer were used. The aim of any coring exercise is to collect an undisturbed and continuous sediment sequence. It was hoped that the records collected in this investigation would provide material from the present day back. It is apparent from the lack of overlap between cores that it is vital that the type and behaviour of the sediment is investigated first to ensure that the most suitable methods are employed. Devices such as glew corers could be employed as these collect very short cores which would increase the possibility of the most recent sediments being captured. In order to ensure an overlap between the Kullenberg and the Livingstone corers, two metre Kullenberg corers could have been deployed. One aspect which needs attention is the amount of weights that are placed on the system. If these are insufficient then the sediment sequences will be mixed as the corer is unable to penetrate the sediment successfully (Davies, pers. com. 2000). A Percussion corer was also employed in this investigation. This was successful in collecting material from solid ground sites. If this device were to be used in a lagoon, an extremely stable platform would have to be constructed with very good anchors so that the system remained in place throughout the operation. This may help recover a longer core from Honey Camp Lagoon as the extra power provided by the engine may be able to penetrate the hard layer that thwarted hand coring attempts in this investigation.

This investigation began as a diatom based study. After the first field season (1999) it became apparent that, as diatom preservation was not a dominant process, this

proxy could not be relied upon to provide a continuous record of change. The methodology employed was therefore widened to include the stable isotopes of oxygen and carbon. From the analysis of the results it is clear that the isotopes have provided the most sensitive results of environmental change. The reasons behind this are twofold. Firstly, because of the location of the records, the diatom flora is dominated by littoral species which appear to have been mainly influenced by habitat rather than chemical changes to the lagoon. Secondly, due to the large size of the New River Lagoon the amount of change needed to result in a complete change of habitat would have to be enormous and thus any smaller-scale changes have not been detected by the diatoms. Stable isotopes respond to wider scale changes of climate and catchment which are more likely to show change. The analysis of the isotope data was, however, hindered by the lack of modern samples which would have enabled a better understanding of the modern environment and created comparative reference conditions. The latter is therefore a priority for future work.

Of key importance to a paleolimnological study is the creation of a chronology which enables the results to be placed into a meaningful context. Dating was problematic in this study principally due to the lack of terrestrial organic matter available in the sediment. In a carbonate area, such as Belize, it is essential that the dating material is terrestrial so that it is not affected by the hardwater error. The organic matter which was dated in the records was very small and thus its integrity in the core was difficult to ascertain. This is especially true of the two dates from Honey Camp Lagoon 1999 which are modern. Funding was awarded to date freshwater gastropods where they occurred at the same depth as terrestrial organic matter i.e. paired dates. Three paired dates have been produced as part of this study. These had hardwater errors of 1105 ^{14}C years BP (Honey Camp Lagoon), 1660 ^{14}C years BP (Lamanai) and 1527 ^{14}C years BP (Hillbank). These are very similar and suggest that these values can be applied as a correction factor to similar lake systems. In order to improve the chronology of the records produced in this study, gastropods should therefore be dated from a number of different horizons and the relevant correction factor applied.

^{210}Pb dating was also carried out in this investigation. This only provided a meaningful record for Hillbank 2000. The two other records analysed did not contain a signal. This is because evidence suggests that Outpost 2000 and Honey Camp 2000 do not contain sediments from the present day back and therefore the signal was lost. The unsupported ^{210}Pb flux from Belize is very low (32 Bq m^{-2} yr^{-1}) compared to the global average (185 Bq m^{-2} yr^{-1}) (Appleby and Oldfield, 1983). The value for Belize compares well with values gained by Davies (2000) for Mexico (Lake Zirahuen: 48 Bq m^{-2} yr^{-1}, Lake Juanacatlan: 12 Bq m^{-2} yr^{-1}). The data from Belize therefore adds weight to Davies' suggestion that the global flux of ^{210}Pb may be more variable than previously thought. ^{210}Pb did not however prove to be a successful dating tool in the New River Lagoon because of the highly mixed nature of the recent Hillbank sediments. This is however useful environmental information which may have been difficult to establish if this technique had not been employed.

It is apparent that the environmental signals detected in records are dependent on the proxies used. It therefore could be argued that until a complete range of tools are employed, any environmental reconstructions cannot be regarded as complete. As well as pollen, the amount and types of gastropods present throughout a sequence could be investigated. This would provide ecological information about the lake environment serving as a valuable addition to the diatom data.

9.6 Wider research issues

The research which is presented in this thesis does not fall solely into one academic discipline; rather, it draws on botany, archaeology and geography. When data are collected it is often done so with specific goals in mind which can be restricting. In terms of the diatom study it became apparent that much more work is needed on species ecology and the role of geography in influencing speciation. The more work that is undertaken in diverse areas the more knowledge that will be gained. Although this thesis may have been hindered by lack of information on this topic, it has made a contribution which will aid further investigations of diatoms in this part of the

Tropics. Most archaeological work in Belize has concentrated on the classification of large temples. While this is very informative in terms of the relative importance of sites, it provides relatively little information about population dynamics and activities. The production of archaeological histories of sites that emphasise human activity rather than the abstract descriptions of archaeological digs would enable a closer link to be developed between lake sediment and human records. The best way in which these goals can be achieved is through collaborative projects. These ensure that maximum information is gleaned from the sites in question.

The first priority for further work in Belize would be to increase the number of dates on each core. This is especially important for Honey Camp Lagoon as it would enable this lagoon to be better integrated into the regional record. More sediment cores should be analysed in order to develop a greater understanding of the role of environment and to develop an improved understanding of the spatial dynamics within systems. To develop the remit further sea level could be investigated to constrain the impact of this variable. An ideal site for this would be Cobweb Swamp. The record from Hillbank is very enlightening because it extends beyond the Holocene. The area which is thought to have the most potential to have a long sediment record is the Booth River Wetlands. There are thought to be permanent water bodies located next to the escarpment which would be ideal for coring producing a long record of environmental change (Furley pers.com. 1999). Access to this area is however very difficult.

Both the New River Lagoon and Honey Camp Lagoon have documented archaeological sites on their shores. Part of the aim of this thesis was to investigate the human history of the area. One way in which this could be enhanced is through the study of sediments from the actual occupation sites. This would include, for example, pits from raised fields. This strategy was undertaken by Bradbury *et al.* (1990). They found, however, that by comparison with the lake record, the field and canal records contained less information. These samples did however provide more insight into the human dynamics of the site.

9.6 The contribution of this thesis

The original focus of this thesis was to address four research questions. The first: to determine the pattern of environmental change in north Belize. This thesis has provided an insight into distinct phases of environmental change, which can be attributed to both climatic and human forces. The second question was to determine whether the records from Belize fit into the wider scale regional patterns. The records from Belize have highlighted most clearly that there are specific difference between various areas of the circum-Caribbean. A greater geographical spread of data is required to develop a better understanding of the regional dynamics of this area. The third aim was to find evidence for the late Holocene dry period. This has been found but its severity is difficult to judge. Evidence from Lamanai suggests that this may have occurred during a period of altered human attitudes to site development, but a causal link between the two cannot be established. This latter point formed part of the fourth aim. The record from Lamanai has not only corroborated known archaeological information it has also added to our appreciation of human impact. This research has also provided evidence of colonial period activity.

The principal conclusions drawn from this thesis are summarised below:

The present day environment of Belize:

1. The lakes sampled in Belize cover a chemical gradient running from calcium bicarbonate, to calcium sulphate to sodium chloride dominated systems. This provides a great deal of scope for comparative studies in the future.
2. From the data available it is apparent that habitat has the most influence over diatom species distribution. This may change, however, with the collection of more water chemistry data. In terms of fossil diatom records, the use of preservation indices increases the amount of data that can be gained from a sequence.

3. Diatom species taxonomy in Belize is a topic in which a great deal of knowledge can be gained concerning the role of environment in determining species characteristics. This was developed in this thesis through the study of *Mastogloia smithii* var. *lacustris*.

The environmental history of Belize:

1. The Lateglacial was a very variable climatic period in Belize.
2. The transition to the Holocene encompassed the most arid conditions seen in the records produced for Belize. This may be a Younger Dryas signal and equates to the signal found in Lake Miragoane, Haiti.
3. The Holocene was a period of stable, moist conditions in Belize in a similar manner to the rest of the circum-Caribbean.
4. Human disturbance is apparent from c. 4900 years BP in Belize.
5. The transition to the late Holocene dry period was gradual. Pollen evidence indicates that this period began in c. 4800 years BP, whilst isotope evidence places it c. 3000 years BP.
6. The record from Lamanai shows clear evidence of human impact on the environment through the building and modifying of temples.
7. The records from Belize show evidence for the late Holocene dry period from 1200 years BP onwards.

This palaeolimnological study presents a picture of dynamic change and spatial variation in northern Belize. The climate of Belize and the surrounding countries of the circum-Caribbean appear to depend on a number of different factors. These factors are related to the strong oceanic influence controlling Belize's climate and the high level of local environmental variation within the country. The findings presented in this thesis have important implications regarding the extent, magnitude, and timing of the climatic changes in the circum-Caribbean during the last ~10,000 years.

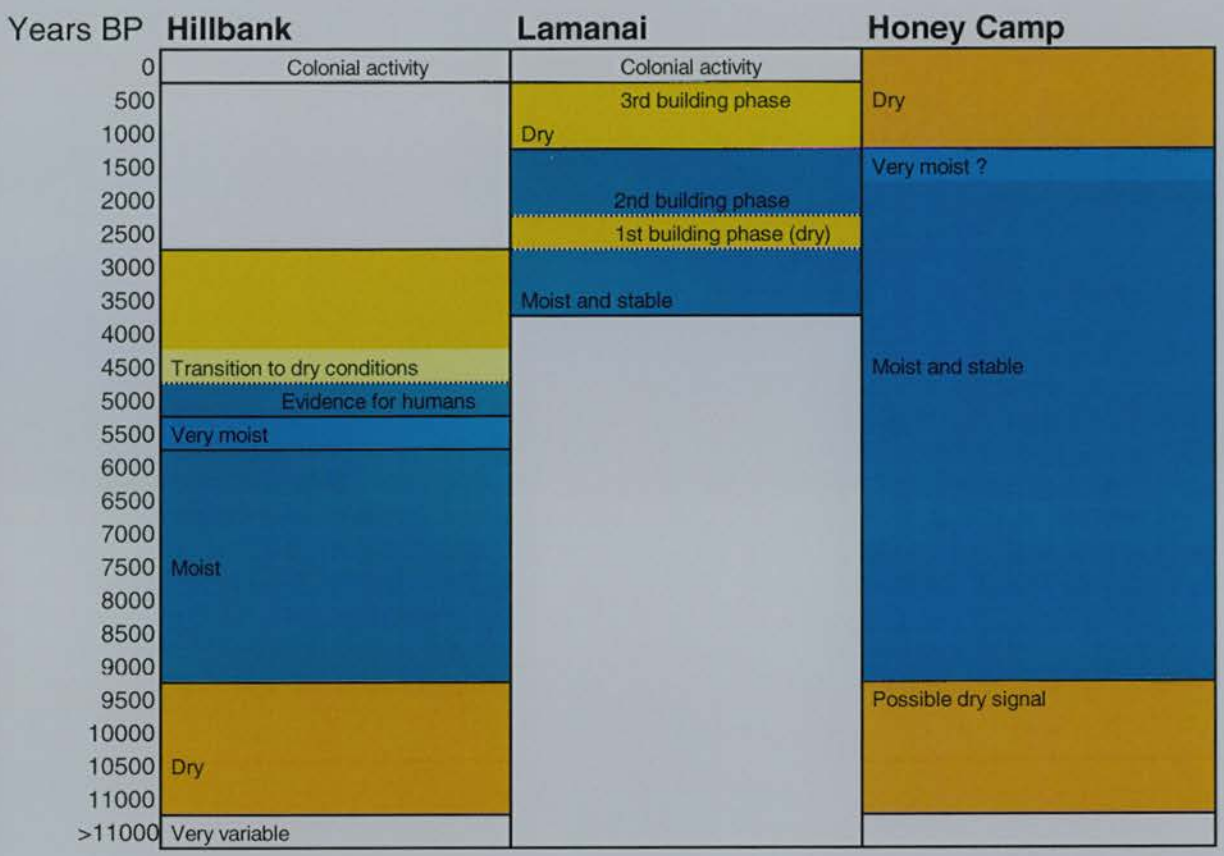


Figure 9.1 A summary of Holocene environmental change in Belize, inferred from this research

Key

moist climate
dry climate
no data available

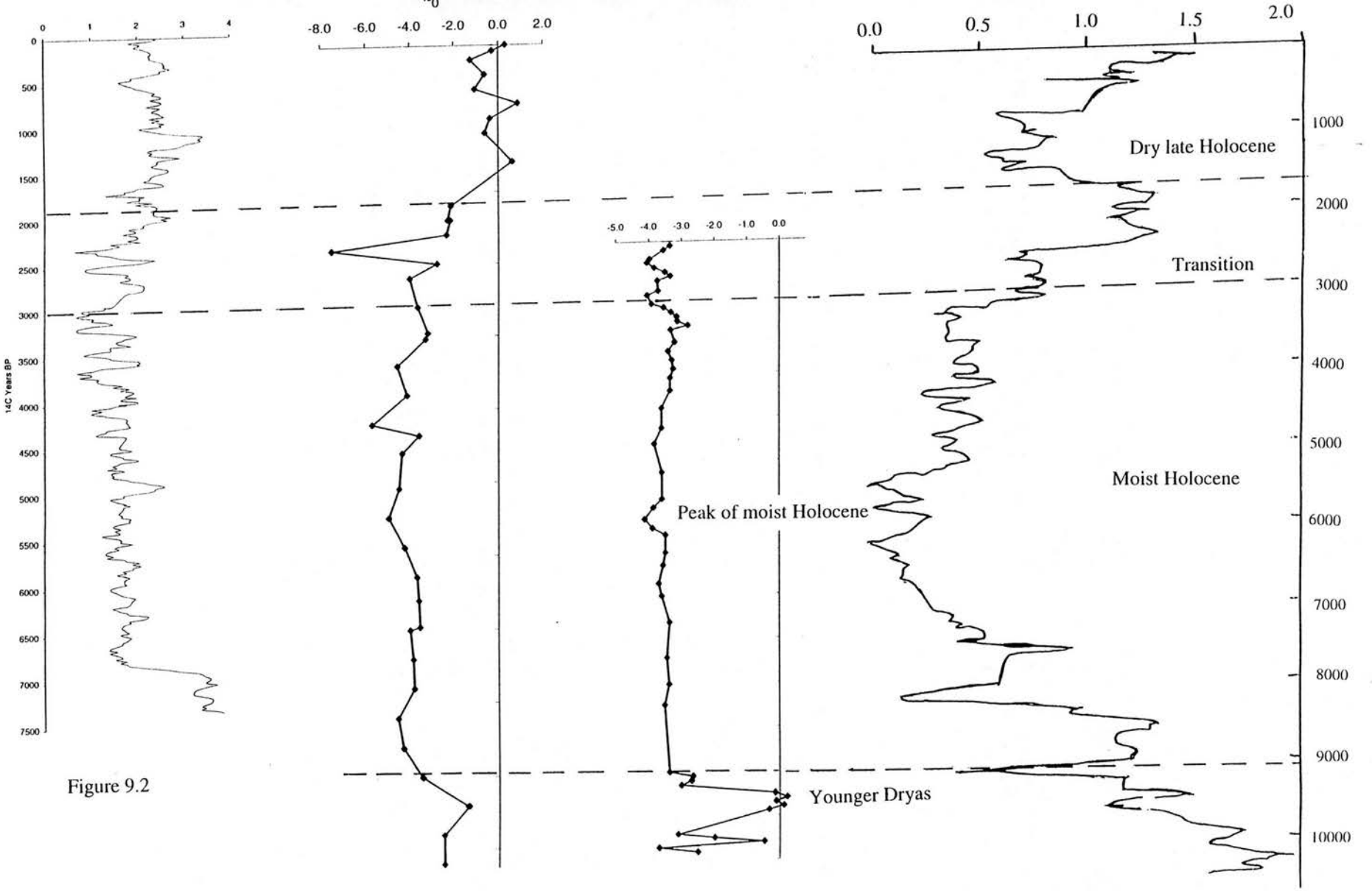

14C Years BP
Dry late Holocene
Transition
Moist Holocene
Peak of moist Holocene
Younger Dryas

Figure 9.2

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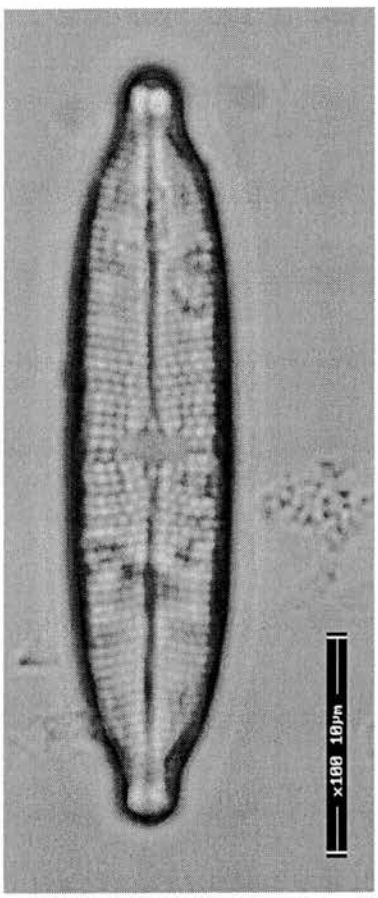
Appendix One:

The following plates are pictures of diatoms species and a selection of the dissolution stages that were encountered in the study of Honey Camp 1999. The species shown cover a variety of forms to provide an overview of the dissolution process in diatoms. The numbers in brackets correspond to the dissolution stage shown.

Mastogloia smithii var lacustris



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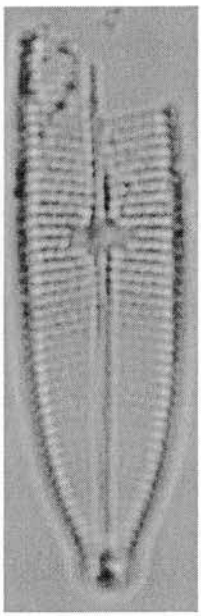

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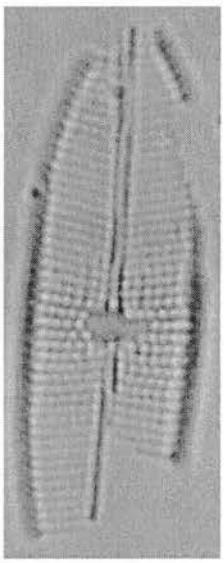

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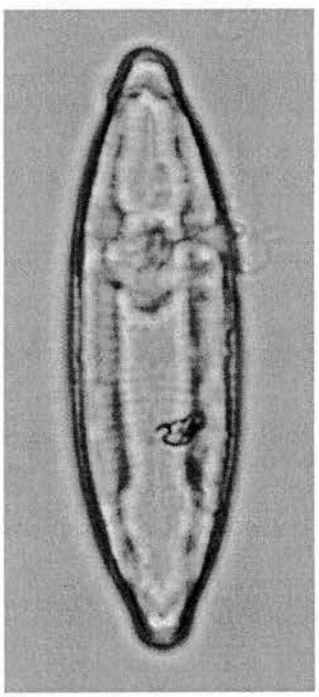
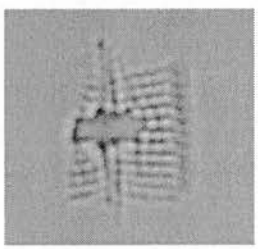
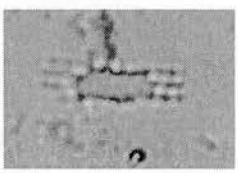


Faint

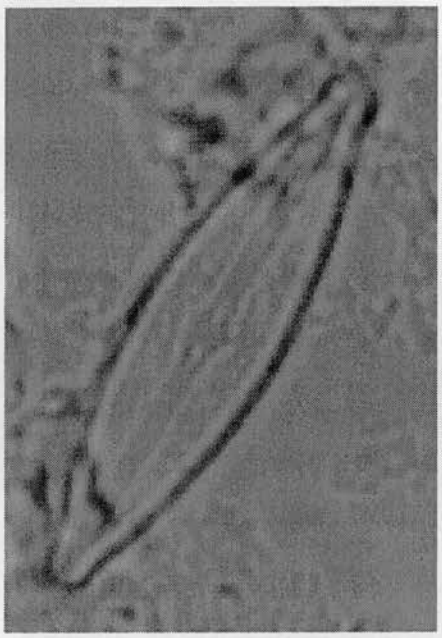


Central area (4)



Central area (4)

Brachysira neoexilis



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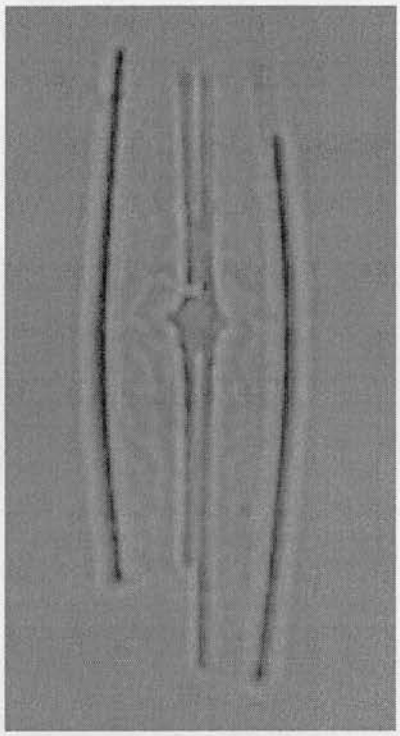

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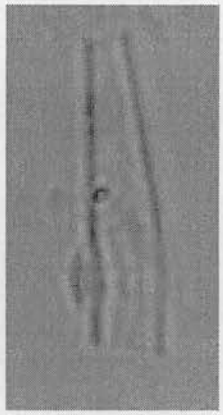
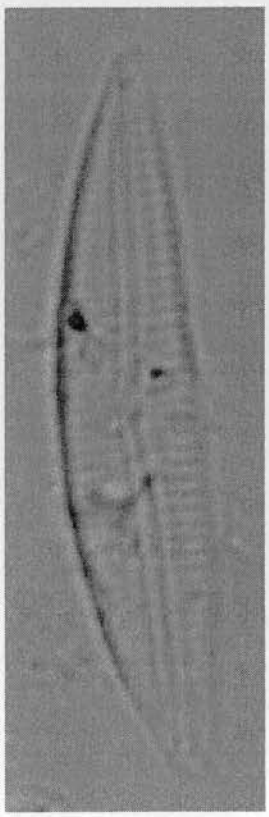


Centre (4)

Encyonema carina



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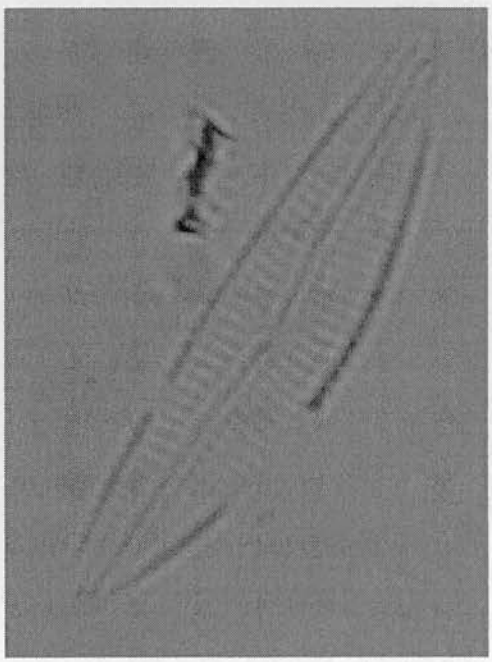

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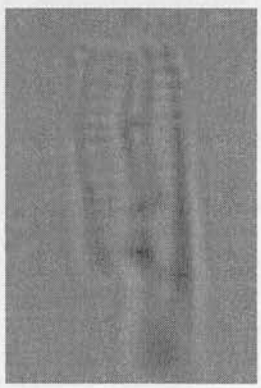

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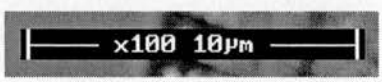
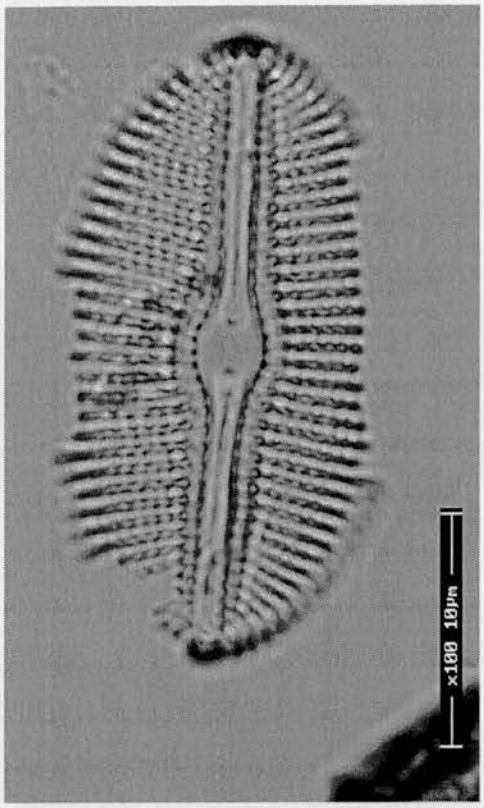


Diploneis elliptica



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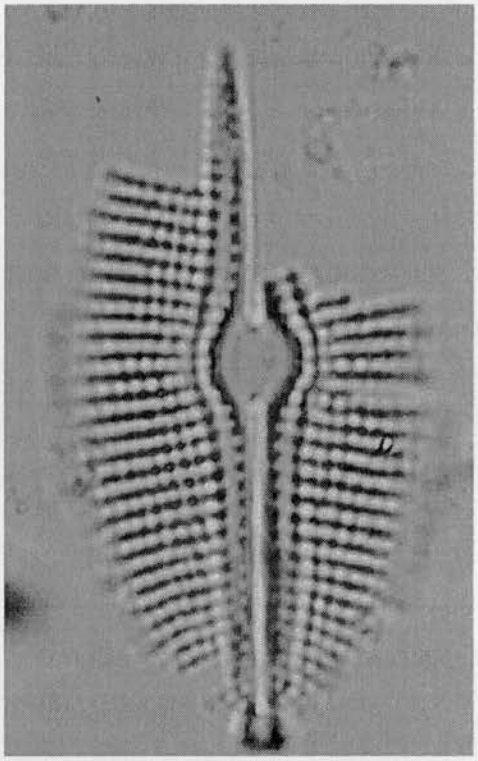

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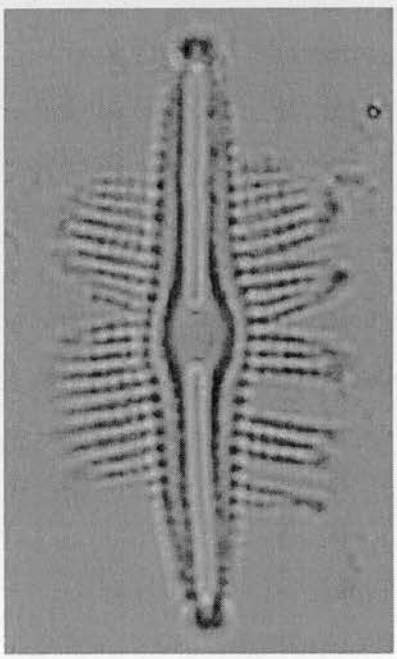

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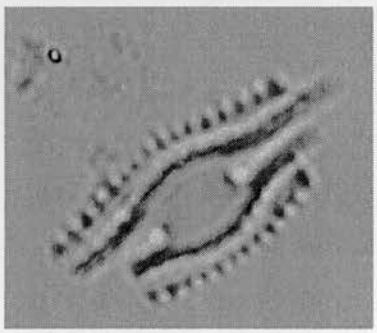
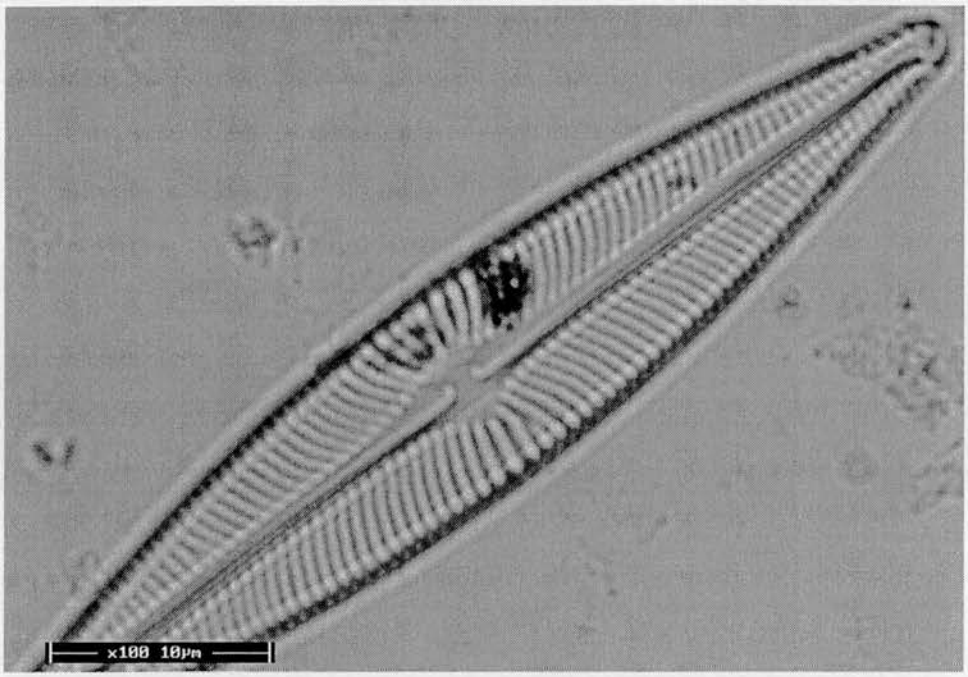


Centre (4)

Navicula radiosa



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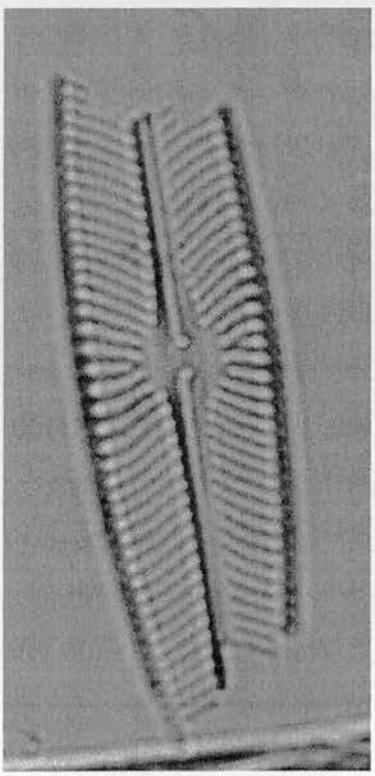

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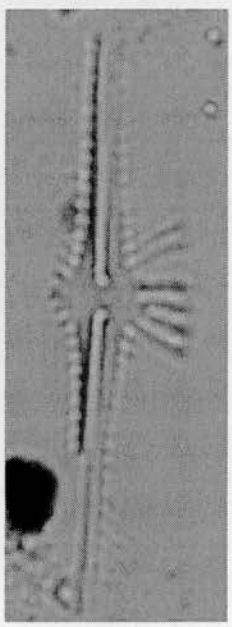


Centre (4)

Centre (4)

Plate One:
A: *Achnanthes exigua*
B: *Achnanthes minutissima*
C: *Brachysira neoexilis* var large
D: *Brachysira neoexilis* var capitate
E: *Brachysira neoexilis* var large capitate
F: *Brachysira neoexilis*
G: *Cymbella microcephala*
H: *Cymbella mesiana*
I: *Cocconeis placentula* var *euglypta*

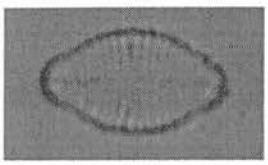
Plate Two:
J: *Denticula elegans*
K: *Denticula tenuis*
L: *Encyonema carina*
M: *Fragilaria fasciculata*
N: *Fragilaria construens*
O: *Gomphonema gracile*

Plate Three:
P: *Mastogloia smithii*
Q: *Mastogloia elliptica* var *dansei*
R: *Gyrosigma acuminatum*
S: Species 15
T: *Navicula florinae*
U: Unidentified species (Almond Hill Lagoon)

Plate Four:
V: *Navicula radiosa*
W: *Navicula radiosa* var *tenella*
X: *Navicula cuspidata*

Plate Five:
Y: *Nitzschia palea*
Z: *Nitzschia amphibia* var *rostrata*
AA: *Nitzschia amphibia*
AB: *Schistauron crucicula*
AC: *Nitzschia gracilis*

A



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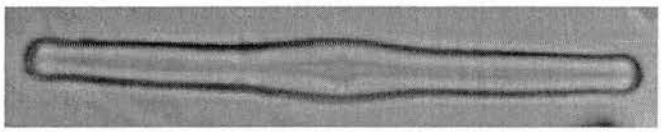

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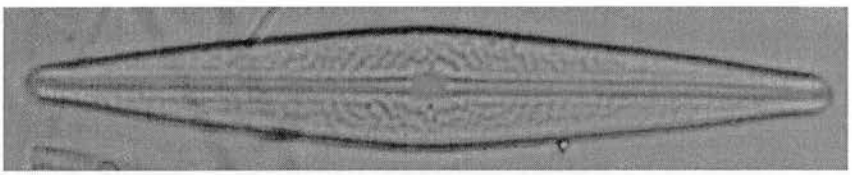

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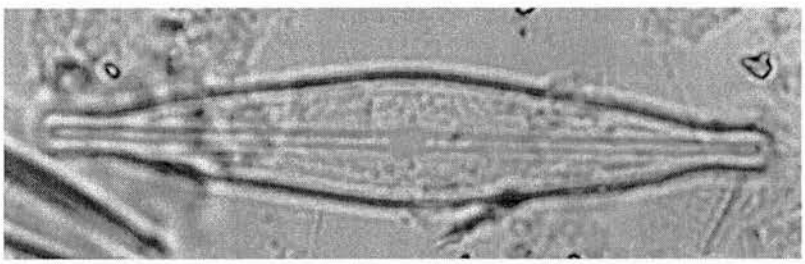

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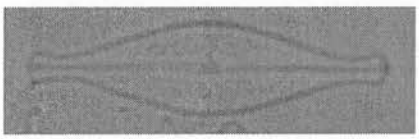

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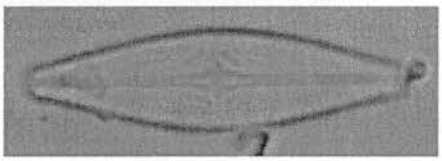

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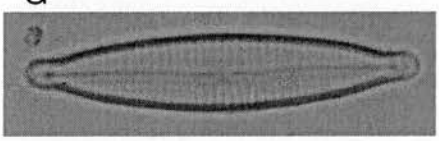

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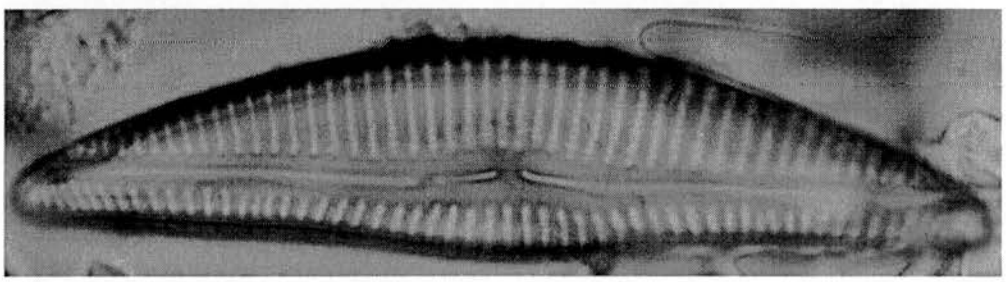

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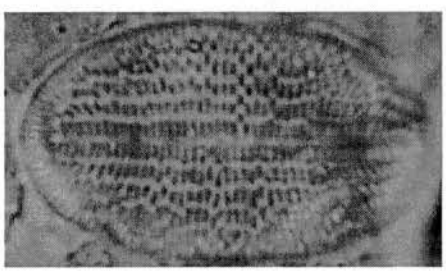

Plate One

Plate Two

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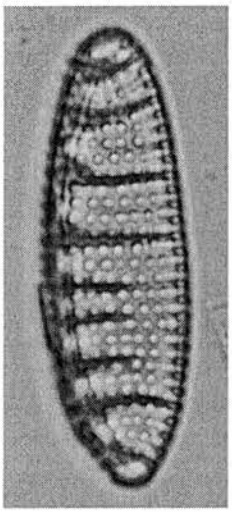

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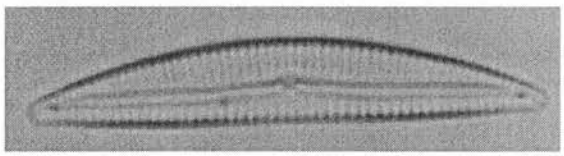

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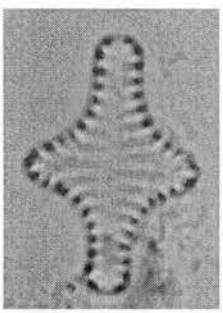

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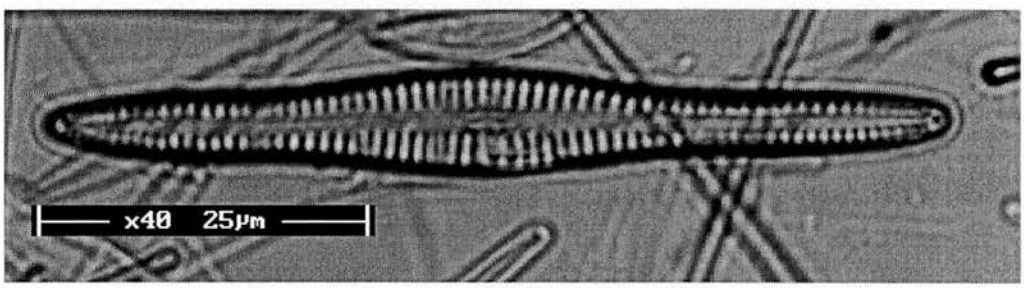

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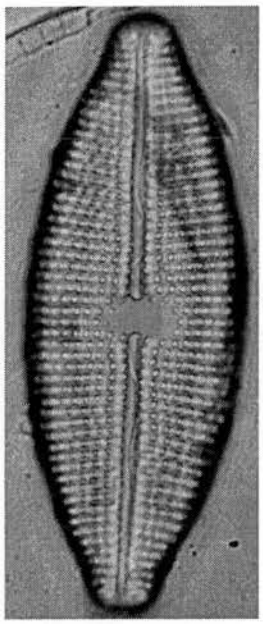
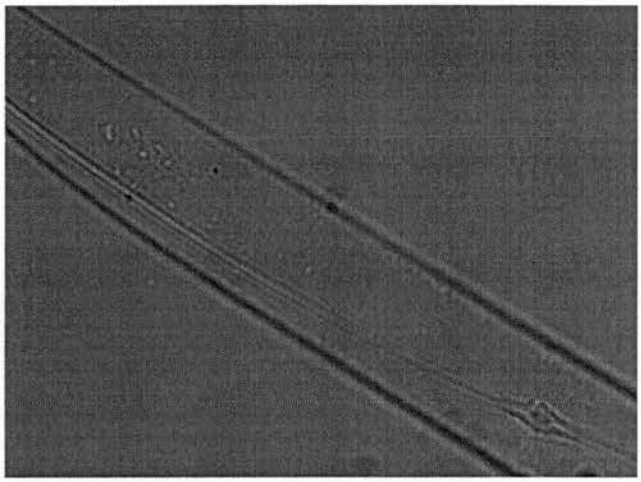


R



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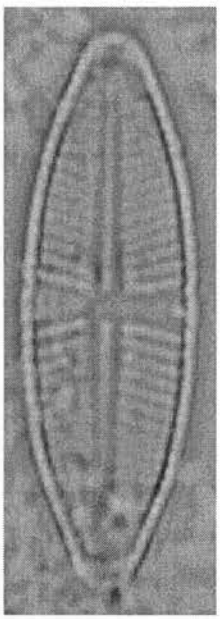

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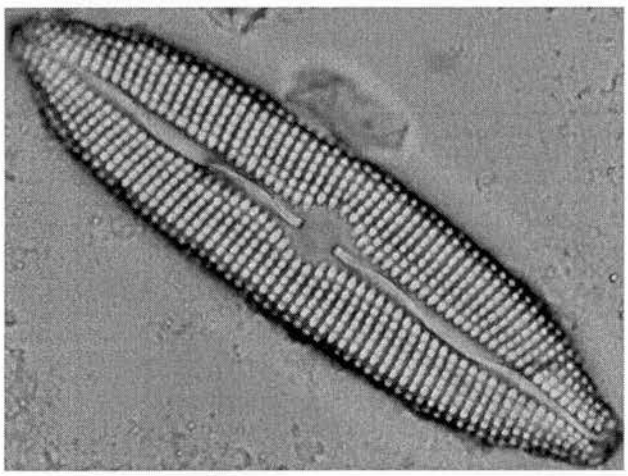

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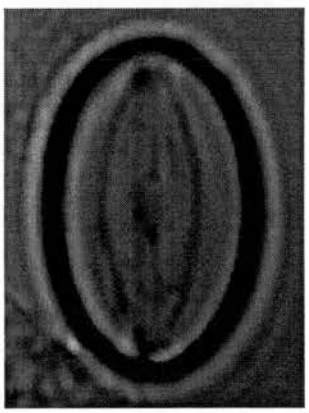

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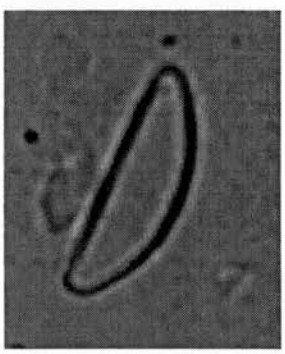
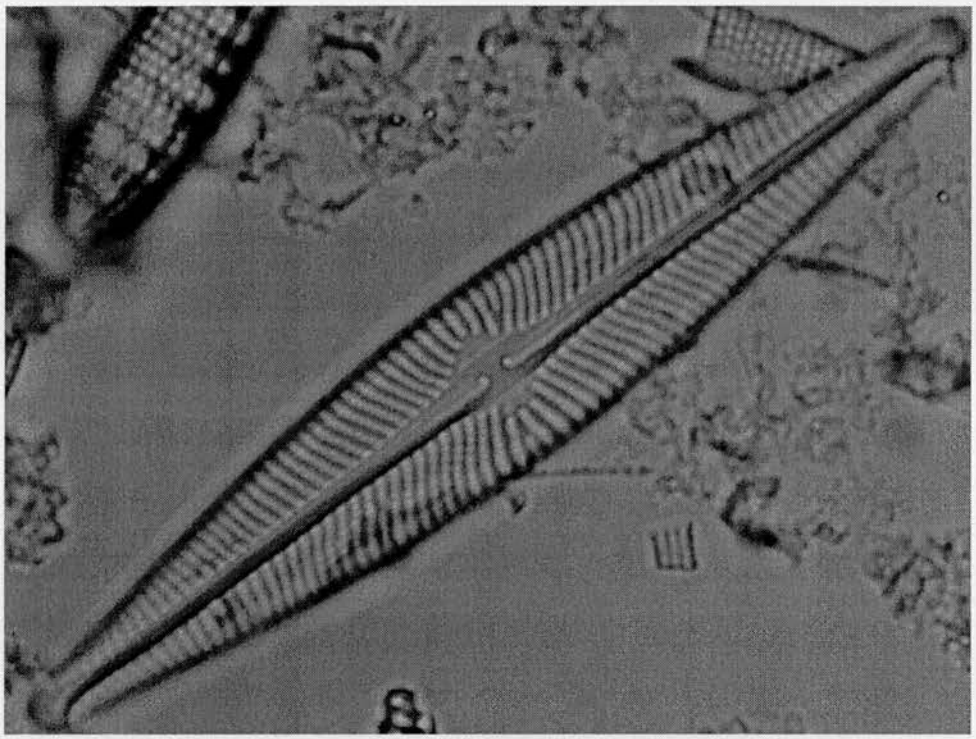


Plate Three

V



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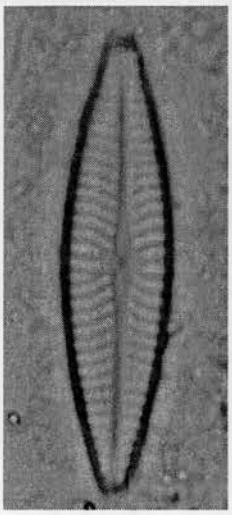

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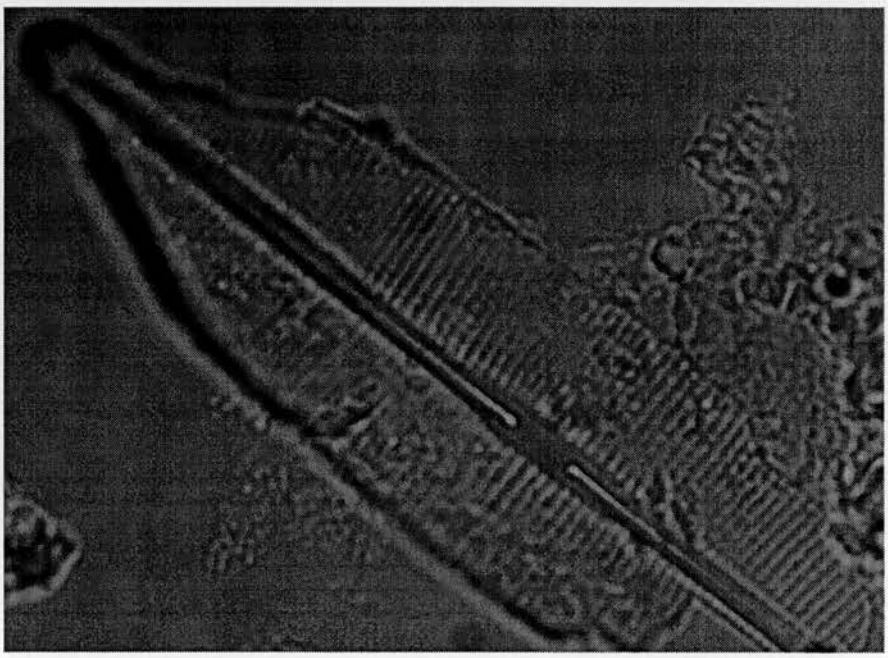
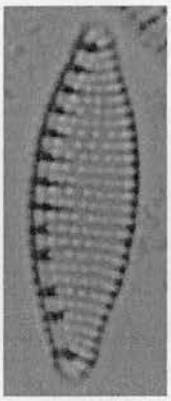


Plate Four

Plate Five

Y

Z



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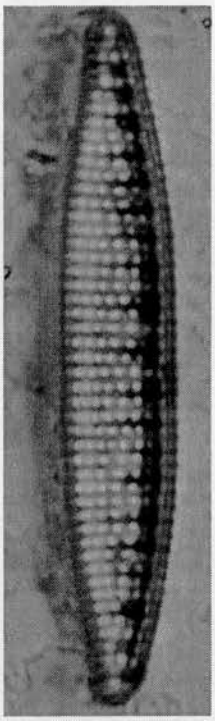

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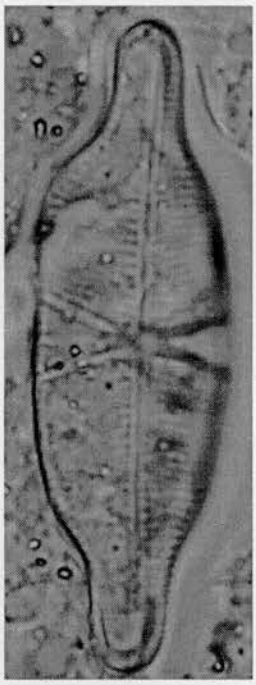

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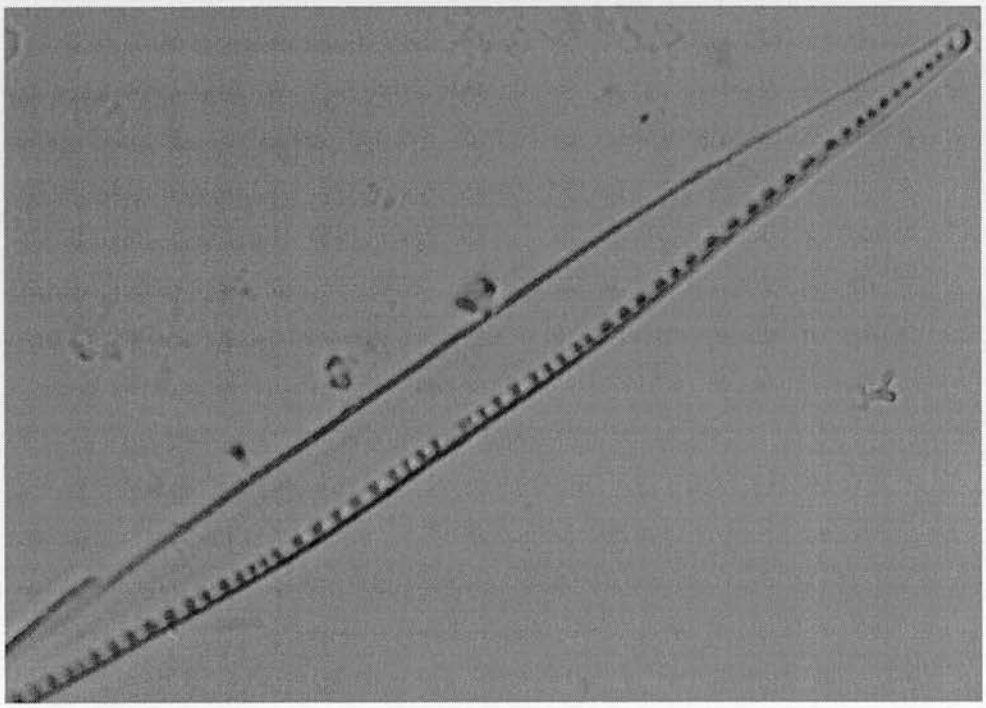

Appendix Three

This section contains a complete list of species encountered in the modern samples collected from sediments, surface water and vegetation from 1998-2000. The sites are listed across the top of each table and the figure in brackets relates to the year of sampling. The figures are in percentages.

SEDIMENT	Species	Authority	Almond Hill (00)	Almond Hill 2 (00)	Booth (98)
AC008D	Achnanthes exigua var elliptica	Hustedt	0.00	0.00	0.00
AC134A	Achnanthes helvetica	(Hustedt) Lange-Bertalot and Krammer 1989	0.00	0.00	0.75
AD009A/XA009X/AC013A	Achnanthes minutissima	Kutzing 1833	4.88	26.04	0.00
AC009A	Achnanthes minutissima variety	/	0.00	0.00	12.25
AC031A	Achnanthes sp	/	0.00	0.00	0.00
AC160A	Achnanthes thermalis	(Rabenhorst) Schoenfeld 1907	0.00	0.00	0.00
AC008A/SS001C	Achnanthes exigua	Grunow in Cleve and Grunow 1880	0.00	0.26	8.00
AP001A	Amphipleura pellucida	Kutzing	0.00	0.00	0.00
AM009C	Amphora clevi	Grunow	0.00	0.00	0.00
AM006A	Amphora coffeaeformis	(Agardh) Kutzing 1844	0.00	0.00	0.00
XM007X	Amphora sp	/	0.00	2.86	0.00
XM009X	Amphora sp 1	/	0.00	0.00	0.00
XM006X	Amphora subturgida var thin	/	0.35	0.00	0.00
AM008A	Amphora thumensis	(A.Mayer) Cleve-Euler 1932	0.00	0.00	0.00
AN009A	Anomoeoneis sphaerophora	(Ehrenberg) Pfitzer 1871	3.83	0.00	0.00
XU009X	Aulacoseira ambigua	(Grunow) Simonsen 1979	0.00	0.00	0.00
AU003A	Aulacoseira granulata	(Ehrenberg) Simonsen 1979	0.00	0.00	6.50
XU008X	Aulacoseira sp	/	16.72	0.78	0.00
BR010A	Brachysira neoexilis	Lange-Bertalot 1994	2.79	2.34	1.50
BR010C/XB020C	Brachysira neoexilis var capitate	/	2.09	3.91	4.25
BR010D	Brachysira neoexilis var large capitate	/	0.00	0.00	0.00
BR010B/XB010B	Brachysira neoexilis var small	/	0.00	0.00	16.00
CO009D	Cocconeis disculus	(Schumann) Cleve in Cleve and Jentzsch 1882	0.00	0.00	0.00
CO001C/XCP001Z	Cocconeis placentula var incisa	Ehrenberg	0.00	0.00	0.00
CO001B	Cocconeis placentula var euglypta	(Ehrenberg 1854) Grunow 1884	0.00	0.00	0.00
CO001A	Cocconeis placentula var placentula	Ehrenberg 1838	0.00	0.00	0.00
CY004A	Cyclotella stelligera	Cleve and Grunow (in Van Heurck) 1882	0.00	0.00	2.75
CM009M/EY010A	Cymbella mesiana	Cholnoky 1955	0.35	0.00	0.00
CM004A	Cymbella microcephala	Grunow in Van Heurck 1880	0.00	0.00	1.00
CM023A	Cymbella pusilla	Grunow in A. Schmidt 1875	0.00	0.00	0.00
EY018A	Cymbella turgida	Gregory 1856	0.00	0.00	0.75
CM110A	Cymbella turgidula	Grunow in A. Schmidt 1875	0.00	0.00	0.00
DE002A	Denticula elegans	Kutzing 1844	0.00	0.00	0.00
DE001A/MUCOO5	Denticula tenuis	Kutzing 1844	0.00	0.00	0.00
DP010A	Diploneis finnica	(Ehrenberg) Cleve 1891	2.44	0.00	0.00
DP007A	Diploneis oblongella	(Naegeli) Cleve-Euler 1922	0.00	0.00	0.00
DP001A	Diploneis ovalis	(Hilse) Cleve 1891	0.00	0.00	0.25
DP065A/MUC007	Diploneis parma	Cleve 1891	0.00	0.00	0.00
DP061A	Diploneis subovalis	Cleve 1894	0.00	1.04	0.00
EC001A/EY016A/EY011A/XE009X	Encyonema carina	Lange-Bertalot and Krammer nov.spec.	9.06	0.00	16.00
EU009C/XN009X	Eunotia camelus	Ehrenberg	0.35	0.00	3.75
EU017A	Eunotia flexuosa	(Brebisson) Kutzing 1849	0.00	0.00	0.00
EU009I/EU047A	Eunotia incisa	Gregory 1854	0.70	0.00	0.00
XS005X	Eunotia incisa variety	/	0.00	31.77	0.00
EU108A	Eunotia intermedia	(Krasske ex Hustedt) Norpel and Lange-Bertalot 1991	0.00	0.00	7.50
EU002A/EU009S	Eunotia solerolii	(Kutzing) Rabenhorst 1864	0.00	0.00	3.50
PS001A	Fragilaria brevistriata	Grunow in Van Heurck 1885	0.00	2.34	0.00
SR001A/FR002A	Fragilaria construens	(Ehrenberg) Grunow 1862	0.00	0.00	0.00
FR057A	Fragilaria fasciculata	(C.Agardh) Lange-Bertalot 1980	0.70	5.21	0.00
SS002A/FR001A	Fragilaria pinnata	Ehrenberg 1843	1.74	0.52	0.00
FR060A	Fragilaria tenera	(W.Smith) Lange-Bertalot 1980	0.35	0.26	0.00
FG001U	Fragilaria ulna	(Nitzsch) Lange-Bertalot 1980	0.00	0.00	0.25
XS014X	Fragillaria construens var javanica	Hustedt 1942	0.00	0.00	0.00
GO004A	Gomphonema gracile	Ehrenberg 1838	4.88	2.34	0.00
GO025B/GO014A	Gomphonema intricatum	Kutzing 1844	0.00	0.00	0.00
GO025H/MUC009	Gomphonema intricatum var vibrio	(Ehrenberg) Cleve	0.00	0.00	2.00
GP009S	Gomphonema sp	/	0.00	0.00	0.00
GY005A	Gyrosigma acuminatum	(Kutzing) Rabenhorst 1853	0.00	0.00	0.00
MA002B	Mastogloia elliptica var dansei	(Thwaites) Cleve 1895	11.85	0.26	0.00
XF009X	Mastogloia smithii var fine	/	9.41	0.26	0.00
MA001B/C/D	Mastogloia smithii var lacustris	Grunow 1878	9.76	0.00	4.25
XF007X	Mastogloia sp	/	10.45	0.00	0.00
NA066B	Navicula capitata var hungarica	(Grunow) Ross 1947	0.70	0.00	0.00
NA008C/NA056A	Navicula cuspidata	(Kutzing) Kutzing 1844	0.00	0.00	0.00
NA365A	Navicula florinae	Moller 1950	0.00	0.00	0.00
SP012S	Navicula florinae variety	/	0.00	0.00	0.00
XH009X	Navicula heimansii	Van Dam and Kooyman 1982	0.00	0.00	0.00
NA102A	Navicula laevissima	Kutzing 1844	0.00	0.00	0.00
NA058A	Navicula phyllepta	Kutzing 1844	0.00	0.00	0.00
NA009P	Navicula pseudosigma		0.00	0.00	0.00
SL001A/NA014A	Navicula pupula	Kutzing 1844	0.00	0.00	0.00
FA001A/NA010A	Navicula pygmea	Kutzing 1849	0.00	0.00	0.00
NA003A	Navicula radiosa	Kutzing 1844	0.70	0.00	0.75
NA751A	Navicula radiosa var tenella	(Brebisson ex Kutzing) Van Heurck 1885	0.00	0.00	3.25
SP009H	Navicula sp	/	0.00	0.00	0.00
UN009S	Navicula sp	/	0.00	0.00	0.00
XN006X/NA650A	Navicula stroemii	Hustedt 1931	0.00	0.00	0.00
XN005X/NA009S	Navicula subtillissima	Cleve 1891	0.35	0.00	0.75
NA144A	Navicula utermoehlii	Hustedt 1943	0.00	0.00	0.00
NE001A	Neidium iridis	(Ehrenberg) Cleve 1894	0.00	0.00	0.00
NI014A/XNA002Z	Nitzschia amphibia	Grunow 1862	2.79	0.52	4.00
XI009X	Nitzschia amphibia var rostrata	Hustedt 1959	2.44	1.04	0.00
NI065A	Nitzschia archibaldii	Lange-Bertalot 1980	0.00	0.00	0.00
NI008A	Nitzschia frustulum	(Kutzing) Grunow in Cleve and Grunow 1880	0.00	0.00	0.00
NI017A	Nitzschia gracilis	Hantzsch 1860	0.00	0.00	0.00
NI009V	Nitzschia levidensis var victorae	(Grunow) Cholnoky 1966	0.00	0.00	0.00
XS007X	Nitzschia liebetruthii	Rabenhorst 1864	0.00	2.86	0.00
NI009A	Nitzschia palea	(Kutzing) W.Smith 1856	0.00	0.00	1.25
NI005S	Nitzschia palea variety	/	0.00	0.00	0.00
XI008X	Nitzschia pellucida	Grunow in Cleve and Grunow 1880	0.00	0.00	0.00
PI009S/MUC013	Pinnularia appendiculata	(Agardh) Cleve 1895	0.00	0.00	0.00
PI008A	Pinnularia divergens	W.Smith 1853	0.00	0.00	0.00
PI005A	Pinnularia major	(Kutzing) Rabenhorst 1853	0.35	0.00	0.00
SV009P	Pinnularia side view (unid)	/	0.00	0.00	0.00
RH001A	Rhopalodia gibba	(Ehrenberg) O.Muller	0.00	0.00	0.00
SS001C	Schistauron crucicula	(Grunow ex Cleve) Ross	0.00	0.00	0.50
NA001P	Species 1 Progresso	/	0.00	0.00	0.00
NI011S	Species 11 South	/	0.00	0.00	0.00
XP014X	Species 14 ahsm	/	0.00	4.69	0.00
SV020C	Sp 20 Chiwa (side view)	/	0.00	0.00	0.00
XS006X	Species 6	/	0.00	2.34	0.00
ST009J	Stephanodiscus minultus	(Kutzing) Cleve and Moller 1878	0.00	0.00	0.00
SR103A	Striatella unipunctata	(Lyngbye) Agardh	0.00	0.00	0.00
SY003A	Synedra acus	Kutzing 1844	0.00	0.00	0.00
SY001A	Synedra ulna	(Nitzsch) Ehrenberg 1832	0.00	0.00	0.00
XU001X	unid side view	/	0.00	0.00	0.00
SV005C	unid side view (sp 5)	/	0.00	0.00	0.00
XM008X	Unid species	/	0.00	0.00	0.00
Total Counted			287	384	400

Booth (99)	Botes (00)	Chiwa (99)	Cobweb (00)	Doubloon (00)	Harry Jones (98)	Harry Jones side (98)	Hillbank 1 (00)	Hillbank 2 (00)	Hillbank 2B (00)	Hillbank 3 (00)	Hillbank far (98)
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	1.77	3.98	0.00	0.00	0.00	0.00	0.50
7.43	1.75	0.00	5.28	1.13	0.00	0.00	5.81	6.21	0.50	0.51	0.00
9.81	0.00	0.26	0.00	0.00	3.79	5.04	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.23	1.01	0.53	0.76	1.67	0.25	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.00	0.00
4.51	0.00	7.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	12.50	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.90	2.25	4.42	7.57	3.17	1.01	6.10	3.54	13.13	9.18	0.25	2.99
1.33	1.75	4.94	9.40	3.62	0.76	9.28	9.34	9.55	0.50	1.01	27.93
1.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.33	1.00	17.14	0.46	0.00	42.42	23.34	0.00	4.06	10.67	0.00	7.23
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.27	2.00	4.94	1.83	4.07	0.00	0.00	1.01	0.72	0.00	0.25	0.00
1.06	0.50	1.30	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	2.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	2.27	0.80	0.00	0.00	0.00	0.00	0.25
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.37	0.00	0.00	3.90	7.47	0.00	0.00	5.81	23.15	53.10	8.84	21.95
1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
0.00	0.00	0.00	1.83	0.23	0.00	0.00	0.25	0.72	0.00	0.00	0.00
0.00	0.00	5.97	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.25
0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.53	2.25	0.00	14.45	33.26	13.89	10.88	9.60	11.93	3.47	3.03	6.98
2.12	2.75	5.45	0.00	0.00	1.01	0.53	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
2.12	0.50	0.52	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12.20	6.25	1.04	0.00	0.00	0.51	2.65	2.78	1.43	0.00	4.04	2.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.27	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00	0.00	0.75
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00
0.53	0.50	1.30	2.75	0.23	0.00	0.00	2.02	2.39	0.00	0.76	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	6.06	3.71	0.00	0.00	0.00	0.00	0.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.24	0.00	3.28	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.85	62.25	24.94	31.19	16.29	11.62	11.94	28.28	8.35	3.72	30.30	16.71
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	1.26	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.50	0.00	2.29	1.58	0.00	0.00	4.04	3.34	0.99	0.00	0.00
0.00	0.00	0.00	1.38	0.00	0.00	0.00	0.25	0.00	0.25	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	5.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.90	0.00	0.00	3.28	0.24	2.73	1.52	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.98	0.00	0.00	2.29	5.20	1.52	1.86	3.79	2.63	6.95	0.76	6.23
0.00	0.00	0.26	0.00	0.00	1.77	3.71	0.00	0.00	0.00	0.00	5.74
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.24	0.00	0.00
0.53	0.00	0.00	8.26	4.52	2.02	1.06	0.00	1.43	1.24	0.00	0.00
0.00	0.00	0.00	0.00	0.00	3.54	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.74	0.25	0.00
0.00	1.25	0.00	1.15	1.36	3.54	2.39	3.28	1.19	0.50	1.01	1.00
0.00	1.50	0.00	0.23	0.45	0.00	0.00	12.12	2.15	3.23	33.84	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	2.26	0.00	3.98	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.27	0.00	0.78	1.38	0.90	0.25	1.59	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.76	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.53	0.00	4.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.33	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	2.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	5.04	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.23	0.00	0.00	0.76	0.48	0.00	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	7.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00
377	400	385	436	442	396	377	396	419	403	396	401

Hillbank this (98)	Honey Camp (00)	Irish Creek (98)	Kates (00)	Kates (99)	Laguna Verde (00)	Lamanai (99)	Monkey Tail (98)	Monkey Tail Stones (98)	Outpost (00)	Rio Bravo (98)
0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.49	0.00	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	10.42	0.00	2.83	0.00	3.45	0.00	0.00	0.00	2.74	0.00
2.20	0.00	1.58	0.00	0.00	0.00	1.11	12.69	0.00	0.00	4.40
0.00	0.00	3.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.79
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.49	4.22	3.43	0.00	0.00	0.49	0.37	0.00	0.00	1.25	3.02
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.95
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.49	4.22	0.00	1.29	4.32	3.69	3.69	0.00	0.00	0.00	0.00
39.27	6.95	0.53	3.86	0.96	0.25	5.54	0.00	0.25	4.24	3.02
0.00	0.00	0.00	0.00	2.40	0.00	1.85	0.00	0.00	0.00	0.00
8.05	1.24	1.58	1.03	4.08	0.49	7.01	0.00	0.25	0.50	5.49
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	3.47	0.00	27.20
0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.73	0.00	15.93
0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
0.00	0.00	0.00	8.48	6.47	13.79	1.48	28.68	5.96	0.00	0.00
0.24	0.00	3.43	0.26	0.00	0.00	0.00	14.21	10.42	0.00	3.57
0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.24	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.71	4.96	0.00	0.00
1.22	0.25	0.00	15.42	26.86	0.49	38.01	0.00	0.00	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	7.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	6.60	0.00	0.00	0.00	0.74	0.00	0.00	0.00	1.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13.90	10.67	4.49	11.31	36.93	47.29	8.86	10.66	2.23	3.24	5.77
0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75
0.00	0.50	5.28	0.26	0.00	0.00	0.00	0.00	0.00	1.25	2.75
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.23	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.06	4.71	0.25	1.37
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
0.98	0.00	1.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.49	0.00	0.51	0.00	0.00	3.32	2.03	0.00	2.99	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.98	0.00	0.00
0.24	0.00	4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	8.44	0.00	0.00
0.00	0.00	7.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
0.00	3.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.71	6.70	1.32	38.56	7.67	0.00	7.75	0.00	0.25	36.91	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.12	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.74	0.00	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.99	0.00	1.03	0.00	5.17	0.00	0.00	0.00	0.25	0.00
0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
0.49	4.96	0.26	4.37	2.16	11.33	7.01	0.25	0.74	0.25	0.00
6.10	0.00	6.60	0.00	0.00	5.17	0.37	3.81	1.49	0.00	7.14
0.00	0.00	6.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.10	0.25	0.00	1.80	1.92	2.96	0.00	0.00	0.00	0.25	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	5.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
7.32	3.97	4.75	0.26	0.00	0.00	5.90	9.14	0.74	4.49	0.00
0.00	9.18	0.00	0.26	0.00	0.74	0.00	0.00	0.00	23.94	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.00	0.25	3.32	0.00	0.00	3.99	0.00
0.00	0.25	0.26	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.27
0.00	0.00	3.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.24	0.00	12.93	0.00	0.00	0.00	1.48	0.00	0.00	0.00	2.47
0.00	0.00	0.00	0.00	6.24	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00
0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00
0.00	0.00	0.00	6.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	19.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
0.00	0.00	0.00	0.00	0.00	1.48	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
410	403	379	389	417	406	271	394	403	401	364

Southern (99)
0.00
0.00
1.16
2.31
0.00
0.00
0.29
0.00
0.00
2.89
0.00
0.00
0.00
0.58
0.00
0.00
0.00
0.00
0.29
0.00
0.00
0.00
3.18
4.91
9.25
3.47
0.00
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0.29
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0.00
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0.00
0.00
0.00
0.00
8.67
0.00
0.87
0.00
0.00
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0.58
0.00
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23.70
21.68
0.00
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2.31
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0.58
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2.31
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0.00
2.02
0.00
0.00
0.00
0.00
0.00
0.58
0.00
0.00
4.91
2.60
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
0.00
346

PLANKTON	Species
SS001C/AC008A	Achnanthes exigua
AD009A/XA009X/AC013A	Achnanthes minutissima
AC009A	Achnanthes minutissima variety
AC160A	Achnanthes thermalis
XU009X	Aulacoseira ambigua
XU008X	Aulacoseira sp
BR010A	Brachysira neoexilis
BR010C/XB020C	Brachysira neoexilis var capitate
BR010E	Brachysira neoexilis var large
XB010B	Brachysira neoexilis var small
CO001B	Cocconeis placentula var euglypta
CO001A	Cocconeis placentula var placentula
EY010A	Cymbella mesiana
CM004A	Cymbella microcephala
DE002A	Denticula elegans
DE001A	Denticula tenuis
EC001A/EY016A/EY011A/XE009X	Encyonema carina
EU009I/EU047A	Eunotia incisa
XN008X	Eunotia side view
FG001U	Fragilaria ulna
GO004A	Gomphonema gracile
GO025H	Gomphonema intricatum var vibrio
MA002B	Mastogloia elliptica var dansei
MA001B/C/D	Mastogloia smithii var lacustris
NA008C	Navicula cuspidata
XH009X	Navicula heimansii
NA123A	Navicula modica
NA003A	Navicula radiosa
NA751A	Navicula radiosa var tenella
UN009S	Navicula sp
XN005X	Navicula subtillissima
NA144A	Navicula utermoehlii
NI014A	Nitzschia amphibia
XI009X	Nitzschia amphibia var rostrata
NA267A	Nitzschia calida
NI017A	Nitzschia gracilis
NI009A	Nitzschia palea
NI009S	Nitzschia silqua
PI009S	Pinnularia appendiculata
PI008A	Pinnularia divergens
PI005A	Pinnularia major
RH001A	Rhopalodia gibba
SU024B	Surirella capronii
SY001A	Synedra ulna

Authority	Aguacaliente	Booth	Botes	Crooked Tree
Grunow in Cleve and Grunow 1880	14.76	0.82	0.00	0.61
Kutzing 1833	0.00	0.00	0.00	0.00
/	0.00	4.95	0.00	2.45
(Rabenhorst) Schoenfeld 1907	0.00	0.00	0.00	0.00
(Grunow) Simonsen 1979	0.00	0.00	0.54	0.00
/	0.00	0.00	0.54	0.00
Lange-Bertalot 1994	0.00	29.40	3.26	65.03
/	0.56	0.00	0.00	0.00
/	0.00	10.71	0.00	1.84
/	0.00	0.00	0.82	0.00
(Ehrenberg 1854) Grunow 1884	0.00	0.00	0.00	0.00
Ehrenberg 1838	0.00	0.00	0.00	0.00
Cholnoky 1955	0.00	0.00	5.43	0.00
Grunow in Van Heurck 1880	0.00	4.95	12.23	0.00
Kutzing 1844	0.00	0.00	0.00	0.00
Kutzing 1844	0.00	2.20	0.00	1.23
Lange-Bertalot and Krammer nov.spe	0.00	14.01	23.37	0.00
Gregory 1854	0.00	0.00	0.82	0.00
/	0.00	0.00	2.99	0.00
(Nitzsch) Lange-Bertalot 1980	0.00	0.00	0.00	3.07
Ehrenberg 1838	0.00	0.00	1.63	0.00
(Ehrenberg) Cleve	0.00	0.00	0.00	0.00
(Thwaites) Cleve 1895	0.00	0.00	0.00	0.00
Grunow 1878	0.00	4.40	15.22	0.00
(Kutzing) Kutzing 1844	2.79	0.27	0.00	0.61
Van Dam and Kooyman 1982	0.00	0.00	13.32	0.00
Husetedt 1945	0.00	0.00	0.00	0.00
Kutzing 1844	0.00	4.95	0.00	0.61
(Brebisson ex Kutzing) Van Heurck 1ε	0.56	9.34	0.00	3.68
/	7.52	0.00	0.00	0.00
Cleve 1891	0.00	0.00	10.33	0.00
Hustedt 1943	0.00	0.00	0.00	0.00
Grunow 1862	0.00	0.00	0.27	0.00
Hustedt 1959	0.00	0.00	0.00	0.00
Grunow in Cleve and Grunow 1880	8.36	0.00	0.00	0.00
Hantzsch 1860	0.00	3.30	0.00	5.52
(Kutzing) W.Smith 1856	56.27	2.20	0.00	13.50
Archibald	5.85	0.00	0.00	0.00
(Agardh) Cleve 1895	0.84	8.52	0.00	1.84
W.Smith 1853	0.00	0.00	7.61	0.00
(Kutzing) Rabenhorst 1853	0.00	0.00	1.36	0.00
(Ehrenberg) O.Muller	0.00	0.00	0.27	0.00
de Brebisson	2.51	0.00	0.00	0.00
(Nitzsch) Ehrenberg 1832	0.00	0.00	0.00	0.00
	359	364	368	163

Doubloon	Harry Jones	Hillbank Centre	Hillbank Far	Irish Creek	Lemonal	Monkey Tail
0.00	0.51	1.03	0.00	0.35	0.36	0.54
16.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	7.65	2.58	1.22	12.89	15.41	1.09
0.00	0.00	0.00	0.00	0.00	0.00	17.39
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.22	38.52	16.28	3.67	15.33	7.17	22.83
19.11	0.51	37.73	51.99	10.10	11.47	5.43
0.00	13.27	12.40	0.00	5.92	4.30	19.57
4.44	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.36	1.09
0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.33	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.78	0.00	0.70	1.08	3.80
0.44	0.26	0.52	3.98	0.70	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
24.44	15.31	11.89	8.26	8.71	7.53	8.70
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	4.34	2.07	2.45	3.48	13.26	4.35
2.22	0.00	0.00	0.00	0.00	0.00	0.00
0.00	6.89	1.29	1.22	0.70	1.43	1.63
0.44	0.00	0.00	0.00	0.00	0.00	0.00
24.00	4.08	4.65	18.65	4.18	1.43	3.26
0.00	0.26	0.26	0.00	0.00	0.00	0.00
0.89	0.00	0.00	0.00	0.00	0.00	0.00
0.00	2.30	0.00	0.00	0.00	0.00	0.00
0.89	1.79	1.29	2.75	1.05	0.72	0.00
0.00	1.02	0.78	2.75	1.39	1.79	5.98
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.44	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	3.36	0.00	2.79	0.36	0.54
0.00	0.00	2.33	1.22	4.88	0.00	1.63
0.89	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.44	2.04	0.26	0.00	3.83	19.35	1.63
0.44	1.28	0.52	1.83	23.00	13.98	0.54
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.33	0.00	0.00	0.00	0.00	0.00	0.00
225	392	387	327	287	279	184

Ramgoat	Rio Bravo
0.00	0.00
0.00	0.00
8.66	14.14
0.00	0.00
0.00	0.00
0.00	0.00
16.27	7.07
19.42	18.94
1.84	1.26
0.00	0.00
0.00	6.82
0.00	6.06
0.00	0.00
1.05	12.63
1.31	0.00
0.00	0.00
34.65	22.47
0.00	0.00
0.00	0.00
1.84	0.51
0.00	2.27
2.89	2.27
0.00	0.00
2.89	1.26
0.00	0.00
0.00	0.00
0.00	0.00
1.57	0.51
4.46	1.26
0.00	0.00
0.00	0.00
0.00	0.00
0.26	0.00
0.00	0.00
0.00	0.00
0.79	0.00
2.10	2.53
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
0.00	0.00
381	396

EPIPHYTE	Species	Authority	Almond Hill (00)
AD009A/AC013A	Achnanthes minutissima	Kutzing 1833	1.74
AC008A/SS001C	Achnathes exigua	Grunow in Cleve and Grunow 1880	0.00
XM007X	Amphora sp	/	1.52
XM006X	Amphora subturgida var thin	/	0.00
XU009X	Aulacoseira ambigua	(Grunow) Simonsen 1979	0.00
XU008X	Aulacoseira sp	/	0.00
BR010A	Brachysira neoexilis	Lange-Bertalot 1994	3.70
BR010C	Brachysira neoexilis var capitate	/	2.61
BR010E	Brachysira neoexilis var large	/	0.00
XB010B	Brachysira neoexilis var small	/	0.43
XY009X	Cyclotella sp	/	1.30
CY004A	Cyclotella stelligera	Cleve and Grunow (in Van Heurck) 1882	0.00
XM009A	Cymbella cesatii	(Rabenhorst) Grunow 1881	0.00
EY010A	Cymbella mesiana	Cholnoky 1955	0.00
CM004A	Cymbella microcephala	Grunow in Van Heurck 1880	0.00
CM023A	Cymbella pusilla	Grunow in A. Schmidt 1875	0.00
DE002A	Denticula elegans	Kutzing 1844	0.00
DE001A/MUC005	Denticula tenuis	Kutzing 1844	0.00
DP007A	Diploneis oblongella	(Naegeli) Cleve-Euler 1922	0.22
DP061A	Diploneis subovalis	Cleve 1894	0.00
EC001A	Encyonema carina	Lange-Bertalot and Krammer nov.spec.	0.00
XN009X	Eunotia camelus	Ehrenberg	0.00
EU017A	Eunotia flexuosa	(Brebisson) Kutzing 1849	0.00
EU047A	Eunotia incisa	Gregory 1854	0.00
XS005X	Eunotia incisa variety	/	0.87
XN008X	Eunotia side view	/	0.00
EU002A	Eunotia solerolii	(Kutzing) Rabenhorst 1864	0.00
SR001A/FR002A	Fragilaria construens	(Ehrenberg) Grunow 1862	0.00
FR057A	Fragilaria fasciculata	(C.Agardh) Lange-Bertalot 1980	71.52
FR060A	Fragilaria tenera	(W.Smith) Lange-Bertalot 1980	1.09
XS014X	Fragillaria construens var javanica	Hustedt 1942	0.00
FU002A	Frustulia rhomboides	(Ehrenberg) de Toni	0.00
GO004A	Gomphonema gracile	Ehrenberg 1838	2.17
MA002B	Mastogloia elliptica var dansei	(Thwaites) Cleve 1895	0.00
MA001A	Mastogloia smithii	Thwaites 1856	0.00
XF009X	Mastogloia smithii var fine	/	0.43
MA001B	Mastogloia smithii var lacustris	Grunow 1878	1.09
XN019X	Nacicula sp 15 ahsm	/	2.39
NA066B	Navicula capitata var hungarica	(Grunow) Ross 1947	0.00
NA001P/NA022A	Navicula halophila	(Grunow) Cleve 1894	0.00
XH009X	Navicula heimansii	Van Dam and Kooyman 1982	0.00
NA102A	Navicula laevissima	Kutzing 1844	0.00
SL001A/NA014A	Navicula pupula	Kutzing 1844	0.00
NA003A	Navicula radiosa	Kutzing 1844	0.00
NA751A	Navicula radiosa var tenella	(Brebisson ex Kutzing) Van Heurck 1885	0.00
XO032X	Navicula sp 32 ahsm	/	1.52
XN006X/NA650A	Navicula stroemii	Hustedt 1931	0.00
XN005X	Navicula subtillissima	Cleve 1891	0.00
NI014A/XNA002Z	Nitzschia amphibia	Grunow 1862	0.00
XI009X	Nitzschia amphibia var rostrata	Hustedt 1959	0.22
NI003A/XND001Z	Nitzschia denticula	Grunow in Van Heurck 1880-1885	0.00
NI008A	Nitzschia frustulum	(Kutzing) Grunow in Cleve and Grunow 18	0.00
NI017A	Nitzschia gracilis	Hantzsch 1860	0.00
XS007X	Nitzschia liebetruthii	Rabenhorst 1864	2.39
NI008N	Nitzschia nana	Grunow in Van Heurck 1881	0.00
NI009A	Nitzschia palea	(Kutzing) W.Smith 1856	0.00
XI008X	Nitzschia pellucida	(Agardh) Cleve 1895	0.00
XI006X	Nitzschia pusilla	Grunow 1862 emend. Lange-Bertalot 1976	1.74
PI009S/MUC013	Pinnularia appendiculata	(Agardh) Cleve 1895	0.00
PI008A	Pinnularia divergens	W.Smith 1853	0.00
PI005A	Pinnularia major	(Kutzing) Rabenhorst 1853	0.00
RH001A	Rhopalodia gibba	(Ehrenberg) O.Muller	0.00
XS006X	Species 6	/	0.22
ST021A	Stephanodiscus minultus	(Kutzing) Cleve and Moller 1878	0.00
SY001A	Synedra ulna	(Nitzsch) Ehrenberg 1832	0.00
XU001X	unid side view	/	0.00
XV009X	unid side view	/	0.65
XM008X	unidentified sp	/	0.00
XS017X	unidentified sp	/	0.43
			460

Almond Hill A (00)	Bluewater (00)	Botes (00)	Botes A (00)	Chiwa (99)	Cobweb (00)	Cobweb A (00)	Doubloon (00)
3.03	7.79	0.50	0.25	0.00	11.89	5.77	29.41
0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	0.00	0.99	21.75	0.00	0.00	0.00	4.48
18.43	14.55	3.72	8.50	13.21	1.86	3.70	4.48
7.58	1.56	2.73	0.25	1.62	7.23	8.78	5.32
0.00	0.00	0.00	0.00	7.55	0.00	0.00	0.00
0.76	9.61	0.74	0.00	0.00	0.00	0.00	1.96
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	2.25	0.00	0.00	0.00	0.00
1.01	0.00	10.67	6.00	0.00	0.70	0.23	1.12
0.00	1.04	18.36	1.25	11.05	0.23	0.46	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28
3.03	9.61	0.00	0.00	0.00	0.23	0.92	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.02	0.00	0.25	0.00	0.00	0.23	0.92	0.00
0.00	1.82	0.00	0.00	0.00	0.00	0.00	0.00
3.79	18.44	26.05	15.00	21.56	51.52	34.18	26.05
0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
0.00	0.00	0.50	6.75	0.00	0.00	0.00	0.00
0.00	0.00	0.50	2.25	0.00	0.00	0.00	0.00
0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56
0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.28
0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.12
44.44	0.00	2.73	0.00	0.00	0.00	0.00	0.00
0.25	7.27	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00
3.79	1.30	1.99	5.75	1.89	0.93	1.62	1.96
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.04	0.78	14.39	11.50	21.29	17.02	24.94	4.48
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.78	9.68	7.00	0.00	0.47	0.69	0.84
0.00	1.56	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.26	0.00	0.25	0.00	0.00	0.00	0.00
0.76	0.52	0.99	0.00	0.00	1.17	0.00	0.56
0.00	0.26	0.00	0.00	6.20	0.00	0.00	0.00
1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	2.73	7.50	0.00	1.17	0.69	0.56
0.00	5.97	1.49	0.00	0.00	0.00	0.46	0.56
0.51	10.91	0.00	0.00	0.00	0.00	0.23	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.82	0.00	0.00	0.00	0.00	0.00	0.28
0.00	0.00	0.25	0.00	0.00	0.00	0.00	1.40
1.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	9.97	0.00	0.00	0.00
0.00	2.08	0.50	0.00	2.16	4.66	15.24	0.84
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00
0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.89
0.00	0.00	0.25	0.25	0.00	0.70	1.15	0.28
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
396	385	403	400	371	429	433	357

Doubloon A (00)	Doubloon B (00)	Hillbank 1A (00)	Hillbank 1B (00)	Hillbank 1C (00)	Hillbank 2A (00)	Hillbank 2C (00)
0.24	1.96	17.69	3.30	12.36	18.51	16.52
0.00	0.00	0.00	0.24	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.24	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.53	7.82	0.87	1.18	6.52	1.58	1.58
5.18	1.71	19.65	11.56	17.75	25.51	16.06
0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.41	2.20	7.86	6.60	12.36	8.58	6.33
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.06	2.20	0.44	0.00	0.45	0.23	1.13
0.00	0.00	0.00	0.47	0.00	0.00	0.00
2.82	2.20	0.00	0.00	0.00	0.00	0.00
3.53	5.62	0.00	1.65	2.70	0.00	0.68
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.49	0.00	0.24	0.22	0.45	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.12	27.14	30.79	28.54	15.96	18.06	20.59
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.45	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.24	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.24	6.11	1.18	3.15	2.71	8.60
0.00	0.24	0.22	0.00	0.00	0.00	0.23
0.24	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.73	0.00	0.00	0.00	0.00	0.00
26.59	19.07	9.39	29.48	4.27	14.67	20.59
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	2.20	2.18	3.30	2.70	3.16	2.04
0.00	0.73	0.00	0.00	0.00	0.00	0.00
0.00	0.24	0.22	0.00	0.22	0.00	0.00
4.00	2.44	0.00	1.65	0.90	0.45	0.45
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.90	0.00
1.88	1.71	0.22	5.42	0.67	1.35	0.23
0.24	1.71	0.00	0.00	0.22	0.00	0.45
0.00	0.49	0.00	0.71	0.22	0.00	0.23
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.98	0.00	0.00	0.00	0.00	0.00
15.76	9.29	0.00	0.00	0.22	0.00	0.23
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.47	3.18	0.44	1.18	0.00	0.23	0.00
0.00	0.24	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.22	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	3.93	3.07	18.88	3.16	4.07
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.29	4.16	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
425	409	458	424	445	443	442

Hillbank 3A (00)	Hillbank 3B(00)	Hillbank 3C (00)	Kates (00)	Kates (99)	Kates A (00)	Laguna Seca (00)
12.16	8.17	18.23	0.00	0.00	0.97	49.33
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.23	0.00	0.00	0.22
0.23	0.72	0.00	6.10	0.00	2.66	0.90
16.97	31.97	15.59	5.16	6.47	6.28	2.24
0.00	0.00	0.00	0.00	4.23	0.00	0.00
5.28	29.33	6.95	1.17	0.00	0.00	3.81
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	4.48
0.00	0.00	0.00	0.00	0.00	0.24	6.05
0.46	0.48	0.48	5.40	0.00	3.14	0.45
0.00	0.00	0.00	0.00	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.06	1.20	0.72	22.54	1.24	3.38	6.73
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.23	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
25.46	9.38	27.34	31.92	67.16	56.28	4.93
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	2.24
0.23	0.00	0.00	0.70	0.00	0.00	0.22
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	2.74	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	2.02
0.23	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.67	3.61	7.43	0.00	0.25	0.24	0.45
0.23	0.00	0.00	0.00	0.00	0.00	0.00
0.23	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
25.00	1.92	18.71	9.39	5.97	9.18	1.35
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.24	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.75	2.88	1.92	0.00	0.00	0.00	2.47
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.23	0.24	0.00	0.00	0.00	0.00	0.00
0.69	1.92	0.00	3.29	0.00	0.24	1.12
0.00	0.00	0.00	0.00	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.46	0.48	0.00	5.16	0.00	0.97	0.45
0.00	0.24	0.48	0.00	0.00	0.00	1.35
0.23	0.48	0.48	0.00	0.00	0.00	0.22
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	3.48	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.62
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.23	1.20	0.24	6.81	0.00	14.73	0.90
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	7.96	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.70	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.52	5.77	1.20	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
436	416	417	426	402	414	446

Laguna Seca A (00)	Laguna Verde (00)	Outpost (00)	Outpost B (00)	Outpost C (00)	Progresso (99)	Progresso 2 (99)
15.72	44.58	18.64	24.19	28.43	0.00	0.00
0.00	0.00	0.00	0.22	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.24	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.90	1.18	0.00	0.22	0.00	1.40	0.00
1.70	0.47	21.79	27.43	35.66	1.40	1.41
0.00	0.00	0.00	0.00	0.00	0.00	0.47
2.65	4.95	2.18	6.70	6.48	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.33	0.00	0.00	0.00	0.00	0.00	0.00
14.77	0.00	0.00	0.00	0.00	0.00	0.00
0.95	2.36	1.94	0.65	1.00	0.00	0.00
1.14	0.00	0.24	0.00	0.00	0.00	1.88
0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.47	0.47	3.63	0.00	0.00	1.68	64.08
0.00	0.00	0.00	0.00	0.00	3.64	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.98	34.67	17.43	14.90	8.48	0.84	6.10
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.22	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.38	0.00	0.00	0.00	0.00	0.00	0.00
0.19	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	85.71	16.20
3.41	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.27	1.65	3.15	1.51	2.74	0.28	1.88
0.00	0.00	0.73	0.22	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.79	0.24	18.16	12.10	2.49	0.56	0.70
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
11.55	1.65	0.00	0.43	1.75	0.00	0.00
0.00	0.00	0.24	0.00	0.00	0.00	0.00
0.19	0.00	0.00	0.00	0.00	0.00	0.00
3.03	0.47	0.48	0.00	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.92	0.47	0.00	0.22	0.00	0.00	0.00
0.76	0.00	5.33	5.40	6.23	0.00	0.00
1.33	0.00	4.84	3.67	3.74	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	7.28
0.00	0.24	0.00	0.43	0.00	0.28	0.00
0.57	0.00	0.00	0.22	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.24	0.00	0.00	0.25	4.20	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	1.21	1.30	2.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	5.90	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
528	424	413	463	401	357	426

Appendix Four: List of diatom samples collected from each lagoon visited (1998-2000)

Code	Water Body	Type	Year	Diatoms Present
PS	Aguacaliente Swamp	S	1999	√
PP	Aguacaliente Swamp	P	1999	√
AY	Almond Hill Lagoon	S	2000	√
AZ	Almond Hill Lagoon	S	2000	√
BA	Almond Hill Lagoon	E	2000	√
BB	Almond Hill Lagoon	S	2000	√
BF	Almond Hill Lagoon	P	2000	X
AS	Bluewater River	E	2000	√
BP	Bluewater River	P	2000	X
BQ	Bluewater River	S	2000	X
OS	Booth River	S	1999	√
OP	Booth River	P	1999	√
XG	Booth River	S	1998	√
X	Botes Lagoon	S	2000	√
Y	Botes Lagoon	E	2000	√
Z	Botes Lagoon	P	2000	√
AA	Botes Lagoon	E	2000	√
BK	Caledonia, New River Lagoon	P	2000	X
LS	Chiwa Lagoon	S	1999	√
LP	Chiwa Lagoon	P	1999	√
LE	Chiwa Lagoon	E	1999	√
BM	Cobweb Swamp	P	2000	X
AL	Cobweb Swamp	E	2000	√
AM	Cobweb Swamp	E	2000	√
AN	Cobweb Swamp	S	2000	√
OD	Crooked Tree Lagoon	P	1999	√
AF	Doubloon Lagoon	E	2000	√
AG	Doubloon Lagoon	E	2000	√
AH	Doubloon Lagoon	S	2000	√
AI	Doubloon Lagoon	St/E	2000	√
AJ	Doubloon Lagoon	P	2000	√
BE	Fabers Lagoon	S	1999	X
XE	Harry Jones Creek	S	1998	√
XEP	Harry Jones Creek	P	1998	√
XF	Harry Jones Creek side	S	1998	√
BI	Hillbank	P	1998	X
XPP	Hillbank centre	P	1998	√
A	Hillbank 1	S	2000	√
B	Hillbank 1	E	2000	√
C	Hillbank 1	E	2000	√

D	Hillbank 1	E	2000	√
F	Hillbank 2	S	2000	√
G	Hillbank 2	E/S	2000	√
H	Hillbank 2	E	2000	√
I	Hillbank 2B	S	2000	√
J	Hillbank 3	S	2000	√
K	Hillbank 3	E	2000	√
L	Hillbank 3	E	2000	√
M	Hillbank 3	E	2000	√
BG	Hillbank 3	P	2000	X
XC	Hillbank far side	S	1998	√
XDP	Hillbank far side	P	1998	√
XD	Hillbank this side	S	1998	√
OA	Honey Camp Lagoon	S	1999	√
U	Honey Camp Lagoon	E	2000	√
V	Honey Camp Lagoon	S	2000	√
BJ	Honey Camp Lagoon	P	1999	X
XH	Irish Creek	S	1998	√
XHP	Irish Creek	P	1998	√
BD	Jones Lagoon	S	1999	X
BS	Kates Lagoon	S	1999	√
BE	Kates Lagoon	E	1999	√
OC	Kates Lagoon	S	1999	√
AC	Kates Lagoon	S	2000	√
AD	Kates Lagoon	S	2000	√
AE	Kates Lagoon	E	2000	√
AC	Kates Lagoon	S	2000	√
AD	Kates Lagoon	S	2000	√
AE	Kates Lagoon	E	2000	√
BL	Kates Lagoon	P	1999	X
AP	Laguna Seca	E	2000	√
AQ	Laguna Seca	E	2000	√
BN	Laguna Seca	S	2000	X
BO	Laguna Seca	P	2000	X
AU	Laguna Verde	E	2000	√
AX	Laguna Verde	S	2000	√
BR	Laguna Verde	S	2000	X
BS	Laguna Verde	P	2000	X
OE	Lamanai	S	1999	√
BH	Lamanai	P	2000	X
XP	Lemonal Creek	P	1998	√
XA	Monkey Tail River	S	1998	√
XI	Monkey Tail River	St	1998	√
XAP	Monkey Tail River	P	1998	√

BC	Northern Lagoon	S	1999	X
O	Outpost	E	2000	√
P	Outpost	S	2000	√
Q	Outpost	E	2000	√
R	Outpost	E	2000	√
MS	Progresso Lagoon	S	1999	√
ME	Progresso Lagoon	E	1999	√
ON	Progresso Lagoon	E	1999	√
XRP	Ramgoat Creek	P	1998	√
XB	Rio Bravo	S	1998	√
XBP	Rio Bravo	P	1998	√
OF	Small Croc Lagoon	S	1999	√
FP	Small Croc Lagoon	P	1999	√
OJ	Southern Lagoon	S	1999	√
OK	Wagner Lagoon	S	1999	X

E: Epiphyte
S: Sediment
P: Plankton
St: Stone scraping
√: Full Diatom Count
X: No Diatoms

The Modern data set (Figure 5.3 and 5.4)

Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7916	0.606	0.4988	0.295		
1	AC00 8A	1.8429	1.5619	0.4001	0.6639	116	7.58
2	AC00 9A	1.5421	1.7047	2.2212	1.1612	450	12.57
3	AC03 1A	0.7432	1.7398	0.2473	1.5258	47	1.77
4	AC13 4A	2.817	1.631	1.165	0.3911	34	3.66
5	AC16 0A	3.4951	2.3254	4.6941	0.5718	33	1.06
6	AD00 9A	4.2695	2.1839	3.5533	1.4773	1772	17.85
7	AM00 6A	-0.4581	1.6581	2.261	1.4296	10	1
8	AN00 9A	5.0024	-1.1694	1.973	4.2024	15	1.72
9	AP00 1A	0.5519	1.707	0.3598	1.5406	18	1
10	AU00 3A	2.8981	1.4652	1.0466	1.7439	73	2.86
11	BR01 0A	3.9243	1.4656	1.9238	0.8395	1516	26.26
12	BR01 0B	2.7767	1.4637	1.5292	0.2284	516	5.61
13	BR01 0C	3.8505	1.5653	2.485	0.015	1610	19.21
14	BR01 0E	4.4215	2.0852	3.1076	1.3281	1825	25.56
15	CM00 4A	2.4864	1.3708	4.5697	2.7377	424	10.24
16	CM02 3A	4.3948	1.4077	0.6533	3.0271	48	4.24
17	CM11 0A	2.2106	1.3181	5.0446	1.5076	74	1.65
18	CO00 1B	-0.0343	1.6552	3.1206	1.4579	181	2.78
19	CO00 1C	-0.4581	1.6581	2.261	1.4296	17	1
20	CO00 9D	-0.4581	1.6581	2.261	1.4296	11	1
21	CY00 4A	3.5384	1.6165	2.3091	0.3177	41	2.92
22	DE00 1A	4.7157	0.7566	1.7999	1.3576	27	2.88
23	DE00 2A	4.6677	-0.2755	1.6164	-0.5642	1461	11.61
24	DP00 1A	2.0526	1.5516	0.3771	1.4214	59	2.94
25	DP00 7A	4.6801	0.6431	1.1652	0.8586	66	4.07
26	DP06 5A	-0.4492	1.644	2.2093	1.4263	31	1.07
27	EC00 1A	3.5152	1.4806	2.2891	1.8523	4855	41.38
28	EU00 2A	4.2194	0.5367	1.2457	2.5428	127	5.01
29	EU00 9C	2.7322	1.5925	1.2693	1.0347	27	2.69
30	EU00 9D	3.3331	1.5665	1.6749	2.8262	38	2.24
31	EU00 9I	3.397	1.1523	1.0015	0.8491	11	1.75
32	EU00 9S	1.6634	1.5906	0.5196	0.5788	32	4.74
33	EU01 7A	4.7161	0.6096	1.3436	3.9307	30	1.23
34	EU04 7A	4.7131	0.1594	1.9244	3.7093	25	5.17
35	EU10 8A	1.3562	1.6835	0.9649	1.3434	40	1.6
36	EY01 0A	3.7257	1.2112	4.1887	2.3927	538	12.4
37	EY01 8A	2.9023	1.6252	1.2999	0.3045	19	3.44
38	FG00 1U	3.2139	1.9014	1.3551	0.6976	124	7.19
39	FR05 7A	5.6078	0.9255	2.9844	0.8244	965	3.9
40	FR06 0A	4.7098	1.8935	1.4687	0.0981	71	3.98
41	FU00 2A	3.8162	1.8666	3.6127	3.2253	13	1
42	GO00 4A	4.2295	1.8889	2.9322	2.8091	434	27.51
43	GO02 5B	1.2475	1.04	5.2689	1.1205	12	1
44	GO02 5H	2.8781	1.8074	1.4683	0.6672	132	8.17
45	GP00 9S	1.2917	1.0606	5.2518	1.149	36	1.12
46	GY00 5A	1.5474	1.8001	0.0994	1.4986	31	1.21
47	MA00 1A	4.5321	1.2311	0.6839	3.4455	21	1.21

48	MA00 1B	4.3222	1.0002	1.6665	2.7151	3366	32.51
49	MA00 2B	5.0375	-0.7369	2.4367	3.8869	65	3.09
50	NA00 1P	-0.4581	1.6581	2.261	1.4296	17	1
51	NA00 3A	4.1812	0.8787	1.8281	0.1031	439	25.21
52	NA00 8C	1.287	1.1042	5.2296	1.1355	216	1.14
53	NA00 9P	3.022	1.4214	0.835	2.3698	21	1
54	NA00 9S	3.5362	1.4772	2.3911	-0.1877	50	3.2
55	NA12 3A	3.7333	2.0631	2.4008	1.2952	9	1
56	NA14 4A	3.4099	1.879	1.6055	0.2352	37	3.18
57	NA26 7A	1.8911	2.2038	-0.473	1.6004	30	1
58	NA36 5A	-0.4581	1.6581	2.261	1.4296	82	1
59	NA75 1A	2.0049	1.6581	2.4795	0.6537	304	15.7
60	NE00 1A	4.7009	0.291	1.0593	-0.0603	28	1.72
61	NI00 3A	5.3407	-2.2509	2.2653	-0.2026	31	1
62	NI00 5S	4.331	0.5366	1.7881	-0.7567	26	1
63	NI00 8A	4.4889	0.5426	1.815	0.4407	59	5.72
64	NI00 8N	3.8162	1.8666	3.6127	3.2253	37	1
65	NI00 9A	2.1232	1.7861	-0.0947	1.9423	743	9.11
66	NI00 9S	1.8911	2.2038	-0.473	1.6004	21	1
67	NI00 9V	1.9213	1.8104	0.0786	1.494	13	1
68	NI01 1S	-0.4581	1.6581	2.261	1.4296	9	1
69	NI01 4A	3.8813	1.2887	2.8842	0.7949	392	21.93
70	NI01 7A	3.7674	1.7397	1.2058	1.7231	285	7.52
71	NI06 5A	-0.4581	1.6581	2.261	1.4296	8	1
72	PI00 8A	4.3852	0.9193	2.0436	3.3304	38	1.77
73	PI00 9S	3.6371	1.6257	1.149	1.696	92	3.46
74	PS00 1A	0.1719	4.9598	2.2286	0.3879	11	1.42
75	RH00 1A	4.6641	0.5132	1.482	2.9006	35	1.88
76	SL00 1A	4.5301	0.3675	1.7895	-0.0485	73	6.46
77	SP00 9H	1.9213	1.8104	0.0786	1.494	25	1
78	SP01 2S	-0.4581	1.6581	2.261	1.4296	75	1
79	SR00 1A	4.9041	-0.1278	2.514	2.6488	44	1.39
80	SR10 3A	3.022	1.4214	0.835	2.3698	9	1
81	SS00 1C	2.0275	1.9617	-0.1782	1.4422	134	2.4
82	ST00 9J	3.022	1.4214	0.835	2.3698	9	1
83	ST02 1A	4.5091	2.4451	3.9365	3.4835	46	1
84	SU02 4B	1.8911	2.2038	-0.473	1.6004	9	1
85	SV00 9P	0.6616	1.2978	0.9819	1.4859	24	1.71
86	SV02 0C	3.1352	1.365	0.8733	2.0496	16	1.75
87	SY00 1A	4.5596	1.928	3.4741	0.9046	233	6.04
88	SY00 3A	2.847	1.6718	1.7998	0.7337	19	1
89	UN00 9S	1.8911	2.2038	-0.473	1.6004	27	1
90	XA00 9X	4.9158	4.9706	2.2654	1.1173	93	1.19
91	XF00 7X	5.1853	-1.7991	2.7368	4.4712	16	1
92	XF00 8X	5.1853	-1.7991	2.7368	4.4712	14	1
93	XF00 9X	4.868	-0.2149	1.3519	3.8131	69	3.45
94	XH00 9X	4.4855	1.4142	2.366	2.6259	386	14.13
95	XI00 6X	6.2057	3.5593	2.7244	2.1689	8	1
96	XI00 9X	4.8421	0.1625	1.8355	0.6357	502	7.32
97	XM00 6X	4.6609	0.2776	0.9539	2.9681	10	1.52
98	XM00 7X	5.3726	4.9367	2.4177	0.7959	18	1.91
99	XM00 8X	4.342	1.4693	0.6043	1.9467	66	2.55
100	XM00 9A	4.7057	1.1969	1.9687	0.6296	115	1.92
101	XN00 5X	4.4365	1.1822	1.4867	3.0212	294	13.58

102	XN00 8X	4.4478	1.6849	3.0205	2.377	25	2.73
103	XN00 9X	4.872	0.2374	1.298	3.8063	13	1.37
104	XN01 9X	5.8214	4.8525	2.5527	1.3582	16	1.86
105	XP01 4X	4.8433	4.9818	2.2213	0.2527	18	1
106	XS00 5X	4.9002	4.9751	2.231	0.2695	129	1.12
107	XS00 6X	5.027	4.9591	2.2437	0.2894	11	1.46
108	XS00 7X	5.521	4.9052	2.3642	0.5758	28	2.82
109	XS01 5X	4.8356	0.0285	1.5438	0.1156	72	4.39
110	XS01 6X	4.9663	4.9712	2.2673	0.3518	11	1.2
111	XS01 7X	5.4664	4.7228	2.1261	0.0552	14	2.09
112	XU00 8X	4.8325	0.1352	1.7614	3.9386	222	3.88
113	XV00 9X	4.5521	2.4571	4.2845	1.4224	35	1.85

Sites

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7916	0.606	0.4988	0.295		
1	BS	3.9676	0.8675	2.0949	0.9149	407	4.2
2	BE	3.7341	1.426	2.2104	1.6446	402	2.13
3	PP	2.0476	1.8832	0	1.728	359	2.85
4	LS	3.2748	1.3319	1.5906	1.7607	380	8.21
5	LE	3.6208	1.4913	2.5434	2.0894	385	7.44
6	OS	3.6438	1.2256	1.8907	1.5807	371	11.07
7	OP	3.5076	1.5269	2.1383	1.3157	364	6.9
8	ME	5.3332	0.9586	2.7504	0.88	357	1.35
9	ON	4.7343	0	2.026	0	426	2.24
10	OJ	0	1.6732	2.299	1.4531	336	7.24
11	OE	4.0515	0.6933	1.8775	0.4998	265	5.34
12	OD	3.509	1.5532	1.6349	1.066	163	2.23
13	XA	3.057	1.3657	3.646	1.8246	394	6.23
14	XB	1.7235	1.5972	2.0852	1.377	364	6.83
15	XC	3.8814	1.0148	1.9728	0.5774	401	5.79
16	XD	3.5306	1.4867	2.2769	0.5521	410	4.86
17	XE	3.1182	1.463	1.7388	0.8562	396	4.49
18	XF	3.1572	1.4772	1.8239	0.9791	377	9.4
19	XG	2.7217	1.5276	1.7043	1.0638	400	10.83
20	XH	2.2369	1.7116	0.8218	1.3562	379	11.67
21	XI	1.946	1.1841	4.6491	1.4116	403	3.54
22	XDP	3.8173	1.3733	2.157	0.7813	327	3.15
23	XHP	3.116	1.6152	1.649	1.2508	287	8.17
24	XAP	3.6078	1.7732	2.7889	1.075	184	7.13
25	XBP	2.9277	1.5526	2.569	1.3915	396	6.06
26	XP	3.0828	1.6977	1.639	1.2366	279	7.99
27	XPP	3.765	1.5803	2.312	0.79	387	4.9
28	XEP	3.5983	1.6044	2.0673	1.1661	392	4.87
29	XRP	3.4132	1.5106	2.1774	1.1253	381	5.07
30	A	4.3048	1.0384	2.1226	1.575	395	7.78
31	B	4.0407	1.7186	2.7102	1.6545	458	5.39
32	C	4.0504	1.3905	2.2069	1.8944	423	5.15
33	D	4.1726	1.6966	2.7867	1.2449	444	7.55
34	F	4.2154	1.0223	2.1292	0.9824	408	8.55
35	G	4.1496	1.712	2.6886	1.6286	439	5.99

36	H	4.1269	1.6254	2.6255	1.792	442	6.59
37	I	4.404	0.3931	1.8159	0.0713	397	3.12
38	J	4.5556	0.4834	1.799	1.4141	389	4.33
39	K	4.1136	1.5133	2.4601	1.8052	435	5.62
40	L	4.1225	1.7443	2.7484	1.0603	416	4.75
41	M	4.0679	1.6334	2.6077	1.7848	416	5.58
42	O	4.1854	1.5141	2.6563	1.6188	412	6.45
43	P	4.4487	0.7789	2.0217	1.8314	399	4.7
44	Q	4.1746	1.7037	2.799	1.5062	463	5.56
45	R	4.2289	1.8406	3.01	1.3735	401	4.41
46	U	4.136	1.0682	1.7825	2.4262	438	3.5
47	V	4.228	1.0873	2.0418	1.2906	372	14.17
48	X	4.3486	0.9093	1.826	2.6921	400	2.44
49	Y	3.7377	1.3291	2.8329	2.2293	403	6.77
50	Z	3.8981	1.2851	2.5049	2.4791	361	7.28
51	AA	4.2845	0.9926	2.1088	2.7461	395	8.58
52	AC	4.2497	0.9101	2.0762	1.8284	388	4.93
53	AD	3.9345	1.019	1.9662	1.3262	420	5.42
54	AE	3.52	1.4536	1.9578	1.8225	407	2.73
55	AF	4.0954	1.7424	2.8473	2.0017	357	5.51
56	AG	3.9284	1.3352	1.7696	1.8972	418	6.18
57	AH	4.0097	1.2134	1.9561	1.7447	435	6.07
58	AI	3.9506	1.2704	1.8642	1.747	402	7.17
59	AJ	4.0966	1.5741	2.5256	1.7947	225	5.46
60	AL	3.7919	1.5281	2.289	1.899	429	3.16
61	AM	3.7011	1.4807	1.9209	1.9603	433	4.64
62	AN	4.1661	1.3057	2.1031	1.9253	422	6.37
63	AP	4.1939	1.7214	2.7664	1.2454	445	3.74
64	AQ	4.2639	1.3361	2.3182	1.2943	528	10.31
65	AS	4.0729	1.2431	2.2048	0.8862	372	9.14
66	AU	3.9891	1.8401	3.0188	1.5757	423	3.05
67	AX	3.6991	1.3155	2.4773	1.5034	395	3.58
68	AY	4.6085	0.3231	2.1778	3.0674	272	10.94
69	AZ	4.7736	4.1841	2.3807	0.7673	363	5.49
70	BA	5.4036	1.4542	2.8567	0.9444	444	1.8
71	BB	4.865	1.3725	2.597	1.0277	392	4

The Modern Data set: Habitat (Figure 5.5)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7916	0.606	0.4988	0.295		
1	AC00 8A	1.8429	1.5619	0.4001	0.6639	116	7.58
2	AC00 9A	1.5421	1.7047	2.2212	1.1612	450	12.57
3	AC03 1A	0.7432	1.7398	0.2473	1.5258	47	1.77
4	AC13 4A	2.817	1.631	1.165	0.3911	34	3.66
5	AC16 0A	3.4951	2.3254	4.6941	0.5718	33	1.06
6	AD00 9A	4.2695	2.1839	3.5533	1.4773	1772	17.85
7	AM00 6A	-0.4581	1.6581	2.261	1.4296	10	1
8	AN00 9A	5.0024	-1.1694	1.973	4.2024	15	1.72
9	AP00 1A	0.5519	1.707	0.3598	1.5406	18	1
10	AU00 3A	2.8981	1.4652	1.0466	1.7439	73	2.86
11	BR01 0A	3.9243	1.4656	1.9238	0.8395	1516	26.26
12	BR01 0B	2.7767	1.4637	1.5292	0.2284	516	5.61
13	BR01 0C	3.8505	1.5653	2.485	0.015	1610	19.21
14	BR01 0E	4.4215	2.0852	3.1076	1.3281	1825	25.56
15	CM00 4A	2.4864	1.3708	4.5697	2.7377	424	10.24
16	CM02 3A	4.3948	1.4077	0.6533	3.0271	48	4.24
17	CM11 0A	2.2106	1.3181	5.0446	1.5076	74	1.65
18	CO00 1B	-0.0343	1.6552	3.1206	1.4579	181	2.78
19	CO00 1C	-0.4581	1.6581	2.261	1.4296	17	1
20	CO00 9D	-0.4581	1.6581	2.261	1.4296	11	1
21	CY00 4A	3.5384	1.6165	2.3091	0.3177	41	2.92
22	DE00 1A	4.7157	0.7566	1.7999	1.3576	27	2.88
23	DE00 2A	4.6677	-0.2755	1.6164	-0.5642	1461	11.61
24	DP00 1A	2.0526	1.5516	0.3771	1.4214	59	2.94
25	DP00 7A	4.6801	0.6431	1.1652	0.8586	66	4.07
26	DP06 5A	-0.4492	1.644	2.2093	1.4263	31	1.07
27	EC00 1A	3.5152	1.4806	2.2891	1.8523	4855	41.38
28	EU00 2A	4.2194	0.5367	1.2457	2.5428	127	5.01
29	EU00 9C	2.7322	1.5925	1.2693	1.0347	27	2.69
30	EU00 9D	3.3331	1.5665	1.6749	2.8262	38	2.24
31	EU00 9I	3.397	1.1523	1.0015	0.8491	11	1.75
32	EU00 9S	1.6634	1.5906	0.5196	0.5788	32	4.74
33	EU01 7A	4.7161	0.6096	1.3436	3.9307	30	1.23
34	EU04 7A	4.7131	0.1594	1.9244	3.7093	25	5.17
35	EU10 8A	1.3562	1.6835	0.9649	1.3434	40	1.6
36	EY01 0A	3.7257	1.2112	4.1887	2.3927	538	12.4
37	EY01 8A	2.9023	1.6252	1.2999	0.3045	19	3.44
38	FG00 1U	3.2139	1.9014	1.3551	0.6976	124	7.19
39	FR05 7A	5.6078	0.9255	2.9844	0.8244	965	3.9
40	FR06 0A	4.7098	1.8935	1.4687	0.0981	71	3.98
41	FU00 2A	3.8162	1.8666	3.6127	3.2253	13	1
42	GO00 4A	4.2295	1.8889	2.9322	2.8091	434	27.51
43	GO02 5B	1.2475	1.04	5.2689	1.1205	12	1
44	GO02 5H	2.8781	1.8074	1.4683	0.6672	132	8.17
45	GP00 9S	1.2917	1.0606	5.2518	1.149	36	1.12
46	GY00 5A	1.5474	1.8001	0.0994	1.4986	31	1.21
47	MA00 1A	4.5321	1.2311	0.6839	3.4455	21	1.21

48	MA00 1B	4.3222	1.0002	1.6665	2.7151	3366	32.51
49	MA00 2B	5.0375	-0.7369	2.4367	3.8869	65	3.09
50	NA00 1P	-0.4581	1.6581	2.261	1.4296	17	1
51	NA00 3A	4.1812	0.8787	1.8281	0.1031	439	25.21
52	NA00 8C	1.287	1.1042	5.2296	1.1355	216	1.14
53	NA00 9P	3.022	1.4214	0.835	2.3698	21	1
54	NA00 9S	3.5362	1.4772	2.3911	-0.1877	50	3.2
55	NA12 3A	3.7333	2.0631	2.4008	1.2952	9	1
56	NA14 4A	3.4099	1.879	1.6055	0.2352	37	3.18
57	NA26 7A	1.8911	2.2038	-0.473	1.6004	30	1
58	NA36 5A	-0.4581	1.6581	2.261	1.4296	82	1
59	NA75 1A	2.0049	1.6581	2.4795	0.6537	304	15.7
60	NE00 1A	4.7009	0.291	1.0593	-0.0603	28	1.72
61	NI00 3A	5.3407	-2.2509	2.2653	-0.2026	31	1
62	NI00 5S	4.331	0.5366	1.7881	-0.7567	26	1
63	NI00 8A	4.4889	0.5426	1.815	0.4407	59	5.72
64	NI00 8N	3.8162	1.8666	3.6127	3.2253	37	1
65	NI00 9A	2.1232	1.7861	-0.0947	1.9423	743	9.11
66	NI00 9S	1.8911	2.2038	-0.473	1.6004	21	1
67	NI00 9V	1.9213	1.8104	0.0786	1.494	13	1
68	NI01 1S	-0.4581	1.6581	2.261	1.4296	9	1
69	NI01 4A	3.8813	1.2887	2.8842	0.7949	392	21.93
70	NI01 7A	3.7674	1.7397	1.2058	1.7231	285	7.52
71	NI06 5A	-0.4581	1.6581	2.261	1.4296	8	1
72	PI00 8A	4.3852	0.9193	2.0436	3.3304	38	1.77
73	PI00 9S	3.6371	1.6257	1.149	1.696	92	3.46
74	PS00 1A	0.1719	4.9598	2.2286	0.3879	11	1.42
75	RH00 1A	4.6641	0.5132	1.482	2.9006	35	1.88
76	SL00 1A	4.5301	0.3675	1.7895	-0.0485	73	6.46
77	SP00 9H	1.9213	1.8104	0.0786	1.494	25	1
78	SP01 2S	-0.4581	1.6581	2.261	1.4296	75	1
79	SR00 1A	4.9041	-0.1278	2.514	2.6488	44	1.39
80	SR10 3A	3.022	1.4214	0.835	2.3698	9	1
81	SS00 1C	2.0275	1.9617	-0.1782	1.4422	134	2.4
82	ST00 9J	3.022	1.4214	0.835	2.3698	9	1
83	ST02 1A	4.5091	2.4451	3.9365	3.4835	46	1
84	SU02 4B	1.8911	2.2038	-0.473	1.6004	9	1
85	SV00 9P	0.6616	1.2978	0.9819	1.4859	24	1.71
86	SV02 0C	3.1352	1.365	0.8733	2.0496	16	1.75
87	SY00 1A	4.5596	1.928	3.4741	0.9046	233	6.04
88	SY00 3A	2.847	1.6718	1.7998	0.7337	19	1
89	UN00 9S	1.8911	2.2038	-0.473	1.6004	27	1
90	XA00 9X	4.9158	4.9706	2.2654	1.1173	93	1.19
91	XF00 7X	5.1853	-1.7991	2.7368	4.4712	16	1
92	XF00 8X	5.1853	-1.7991	2.7368	4.4712	14	1
93	XF00 9X	4.868	-0.2149	1.3519	3.8131	69	3.45
94	XH00 9X	4.4855	1.4142	2.366	2.6259	386	14.13
95	XI00 6X	6.2057	3.5593	2.7244	2.1689	8	1
96	XI00 9X	4.8421	0.1625	1.8355	0.6357	502	7.32
97	XM00 6X	4.6609	0.2776	0.9539	2.9681	10	1.52
98	XM00 7X	5.3726	4.9367	2.4177	0.7959	18	1.91
99	XM00 8X	4.342	1.4693	0.6043	1.9467	66	2.55
100	XM00 9A	4.7057	1.1969	1.9687	0.6296	115	1.92
101	XN00 5X	4.4365	1.1822	1.4867	3.0212	294	13.58

102	XN00 8X	4.4478	1.6849	3.0205	2.377	25	2.73
103	XN00 9X	4.872	0.2374	1.298	3.8063	13	1.37
104	XN01 9X	5.8214	4.8525	2.5527	1.3582	16	1.86
105	XP01 4X	4.8433	4.9818	2.2213	0.2527	18	1
106	XS00 5X	4.9002	4.9751	2.231	0.2695	129	1.12
107	XS00 6X	5.027	4.9591	2.2437	0.2894	11	1.46
108	XS00 7X	5.521	4.9052	2.3642	0.5758	28	2.82
109	XS01 5X	4.8356	0.0285	1.5438	0.1156	72	4.39
110	XS01 6X	4.9663	4.9712	2.2673	0.3518	11	1.2
111	XS01 7X	5.4664	4.7228	2.1261	0.0552	14	2.09
112	XU00 8X	4.8325	0.1352	1.7614	3.9386	222	3.88
113	XV00 9X	4.5521	2.4571	4.2845	1.4224	35	1.85

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7916	0.606	0.4988	0.295		
1	BS	3.9676	0.8675	2.0949	0.9149	407	4.2
2	BE	3.7341	1.426	2.2104	1.6446	402	2.13
3	PP	2.0476	1.8832	0	1.728	359	2.85
4	LS	3.2748	1.3319	1.5906	1.7607	380	8.21
5	LE	3.6208	1.4913	2.5434	2.0894	385	7.44
6	OS	3.6438	1.2256	1.8907	1.5807	371	11.07
7	OP	3.5076	1.5269	2.1383	1.3157	364	6.9
8	ME	5.3332	0.9586	2.7504	0.88	357	1.35
9	ON	4.7343	0	2.026	0	426	2.24
10	OJ	0	1.6732	2.299	1.4531	336	7.24
11	OE	4.0515	0.6933	1.8775	0.4998	265	5.34
12	OD	3.509	1.5532	1.6349	1.066	163	2.23
13	XA	3.057	1.3657	3.646	1.8246	394	6.23
14	XB	1.7235	1.5972	2.0852	1.377	364	6.83
15	XC	3.8814	1.0148	1.9728	0.5774	401	5.79
16	XD	3.5306	1.4867	2.2769	0.5521	410	4.86
17	XE	3.1182	1.463	1.7388	0.8562	396	4.49
18	XF	3.1572	1.4772	1.8239	0.9791	377	9.4
19	XG	2.7217	1.5276	1.7043	1.0638	400	10.83
20	XH	2.2369	1.7116	0.8218	1.3562	379	11.67
21	XI	1.946	1.1841	4.6491	1.4116	403	3.54
22	XDP	3.8173	1.3733	2.157	0.7813	327	3.15
23	XHP	3.116	1.6152	1.649	1.2508	287	8.17
24	XAP	3.6078	1.7732	2.7889	1.075	184	7.13
25	XBP	2.9277	1.5526	2.569	1.3915	396	6.06
26	XP	3.0828	1.6977	1.639	1.2366	279	7.99
27	XPP	3.765	1.5803	2.312	0.79	387	4.9
28	XEP	3.5983	1.6044	2.0673	1.1661	392	4.87
29	XRP	3.4132	1.5106	2.1774	1.1253	381	5.07
30	A	4.3048	1.0384	2.1226	1.575	395	7.78
31	B	4.0407	1.7186	2.7102	1.6545	458	5.39
32	C	4.0504	1.3905	2.2069	1.8944	423	5.15
33	D	4.1726	1.6966	2.7867	1.2449	444	7.55
34	F	4.2154	1.0223	2.1292	0.9824	408	8.55

35	G	4.1496	1.712	2.6886	1.6286	439	5.99
36	H	4.1269	1.6254	2.6255	1.792	442	6.59
37	I	4.404	0.3931	1.8159	0.0713	397	3.12
38	J	4.5556	0.4834	1.799	1.4141	389	4.33
39	K	4.1136	1.5133	2.4601	1.8052	435	5.62
40	L	4.1225	1.7443	2.7484	1.0603	416	4.75
41	M	4.0679	1.6334	2.6077	1.7848	416	5.58
42	O	4.1854	1.5141	2.6563	1.6188	412	6.45
43	P	4.4487	0.7789	2.0217	1.8314	399	4.7
44	Q	4.1746	1.7037	2.799	1.5062	463	5.56
45	R	4.2289	1.8406	3.01	1.3735	401	4.41
46	U	4.136	1.0682	1.7825	2.4262	438	3.5
47	V	4.228	1.0873	2.0418	1.2906	372	14.17
48	X	4.3486	0.9093	1.826	2.6921	400	2.44
49	Y	3.7377	1.3291	2.8329	2.2293	403	6.77
50	Z	3.8981	1.2851	2.5049	2.4791	361	7.28
51	AA	4.2845	0.9926	2.1088	2.7461	395	8.58
52	AC	4.2497	0.9101	2.0762	1.8284	388	4.93
53	AD	3.9345	1.019	1.9662	1.3262	420	5.42
54	AE	3.52	1.4536	1.9578	1.8225	407	2.73
55	AF	4.0954	1.7424	2.8473	2.0017	357	5.51
56	AG	3.9284	1.3352	1.7696	1.8972	418	6.18
57	AH	4.0097	1.2134	1.9561	1.7447	435	6.07
58	AI	3.9506	1.2704	1.8642	1.747	402	7.17
59	AJ	4.0966	1.5741	2.5256	1.7947	225	5.46
60	AL	3.7919	1.5281	2.289	1.899	429	3.16
61	AM	3.7011	1.4807	1.9209	1.9603	433	4.64
62	AN	4.1661	1.3057	2.1031	1.9253	422	6.37
63	AP	4.1939	1.7214	2.7664	1.2454	445	3.74
64	AQ	4.2639	1.3361	2.3182	1.2943	528	10.31
65	AS	4.0729	1.2431	2.2048	0.8862	372	9.14
66	AU	3.9891	1.8401	3.0188	1.5757	423	3.05
67	AX	3.6991	1.3155	2.4773	1.5034	395	3.58
68	AY	4.6085	0.3231	2.1778	3.0674	272	10.94
69	AZ	4.7736	4.1841	2.3807	0.7673	363	5.49
70	BA	5.4036	1.4542	2.8567	0.9444	444	1.8
71	BB	4.865	1.3725	2.597	1.0277	392	4

1999 Water Chemistry (Figures 5.6 and 5.7)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.8685	0.4345	0.1873	0.0572		
1	AC00 8A	6.0505	0.907	1.7536	1.6074	9	1.59
2	AC00 9A	4.0815	1.7814	1.9277	2.5507	71	2.83
3	AC16 0A	1.7378	2.3539	2.9474	2.8895	1	1
4	AD00 9A	4.7594	2.2492	2.8499	2.7834	32	1.28
5	AM00 6A	6.6995	1.0279	1.5963	1.6639	10	1
6	AU00 3A	1.2366	3.5978	2.3431	3.5019	47	1.86
7	BR01 0A	1.5072	1.0324	-0.3089	0.6992	339	4.34
8	BR01 0B	0.8667	3.0786	1.3666	2.6497	107	2.28
9	BR01 0C	0.8795	1.3978	2.309	2.5641	88	5.52
10	BR01 0E	1.3366	0.0951	2.7561	2.1563	89	3.04
11	CM00 4A	1.4579	1.2123	3.5304	2.1803	78	2.88
12	CO00 1B	6.6995	1.0279	1.5963	1.6639	32	1
13	CO00 1C	6.6995	1.0279	1.5963	1.6639	17	1
14	CO00 9D	6.6995	1.0279	1.5963	1.6639	11	1
15	DE00 1A	0.4728	1.7254	0.3392	0.1047	27	2.88
16	DE00 2A	0.3048	-0.1341	1.9637	2.6356	523	2.78
17	DP00 1A	0.897	4.059	1.5029	3.6927	25	1.17
18	DP06 5A	6.6951	1.1019	1.6904	1.7603	31	1.07
19	EC00 1A	1.5667	-0.414	2.2115	0.8685	674	4.14
20	EU00 2A	1.6804	2.5234	2.8802	2.9662	50	1.17
21	EU00 9C	1.7378	2.3539	2.9474	2.8895	5	1
22	EU00 9D	1.1106	3.1897	3.095	2.8721	38	2.24
23	EU00 9I	1.5036	2.6293	2.7584	2.9737	11	1.75
24	EY01 0A	0.8006	1.8399	0.4898	-0.0667	51	2.35
25	FG00 1U	1.739	1.3722	-1.9703	0.0583	6	1.38
26	FR05 7A	-0.2627	1.8171	0.9259	-0.202	386	1.51
27	FU00 2A	1.2394	1.0848	4.609	0.3128	13	1
28	GO00 4A	1.3303	1.6021	2.8759	2.7368	34	5.12
29	MA00 1B	1.2004	2.2912	2.8116	2.3038	330	5.21
30	NA00 1P	6.6995	1.0279	1.5963	1.6639	17	1
31	NA00 3A	1.1815	0.4143	1.9494	1.083	62	3.88
32	NA00 8C	3.1073	0.9237	0.3416	1.4438	12	1.41
33	NA00 9P	0.9262	4.2929	1.3876	3.8489	21	1
34	NA00 9S	0.9229	-0.484	0.3142	-1.2371	10	1.47
35	NA26 7A	3.6204	1.0279	1.5963	1.6639	30	1
36	NA36 5A	6.6995	1.0279	1.5963	1.6639	82	1
37	NA75 1A	2.0417	0.5522	2.4474	1.4897	70	2.83
38	NI00 3A	0.0101	-0.0731	2.4881	4.535	31	1
39	NI00 5S	0.7131	-0.9933	0.023	-1.9288	26	1
40	NI00 8A	0.8473	-0.477	2.0489	2.3881	24	2.07
41	NI00 8N	1.2394	1.0848	4.609	0.3128	37	1
42	NI00 9A	3.4127	1.1809	0.472	1.065	270	1.75
43	NI00 9S	3.6204	1.0279	1.5963	1.6639	21	1
44	NI01 1S	6.6995	1.0279	1.5963	1.6639	9	1
45	NI01 4A	0.5762	0.2181	2.5458	1.2135	16	1
46	NI01 7A	1.6196	0.4253	-0.8272	0.9294	21	1.96
47	NI06 5A	6.6995	1.0279	1.5963	1.6639	8	1

48	PI00 9S	1.5121	0.088	1.6026	2.6488	92	3.46
49	PS00 1A	6.6995	1.0279	1.5963	1.6639	2	1
50	SP01 2S	6.6995	1.0279	1.5963	1.6639	75	1
51	SR10 3A	0.9262	4.2929	1.3876	3.8489	9	1
52	SS00 1C	3.3551	0.9539	1.2158	1.6757	50	1.18
53	ST00 9J	0.9262	4.2929	1.3876	3.8489	9	1
54	SU02 4B	3.6204	1.0279	1.5963	1.6639	9	1
55	SV00 9P	2.5839	3.6725	1.7855	3.4556	24	1.71
56	SV02 0C	1.1949	3.6923	2.2585	3.5491	16	1.75
57	UN00 9S	3.6204	1.0279	1.5963	1.6639	27	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.8685	0.4345	0.1873	0.0572		
1	PP	3.4609	1.0908	0.8918	1.3334	359	2.85
2	BS	1.0255	0.2329	1.7476	1.2738	407	4.2
3	BE	1.3958	0	2.1898	1.3151	402	2.13
4	OD	1.8639	0.999	0	0.8845	163	2.23
5	OE	0.9015	0.6521	1.9636	2.1129	265	5.34
6	LS	1.1759	2.8419	1.9575	2.6491	380	8.21
7	LE	1.4483	1.0169	2.529	1.4771	385	7.44
8	ON	0.3286	0.2669	1.91	2.1941	426	2.24
9	ME	0	1.7142	0.935	0	357	1.35
10	OJ	6.1985	1.0244	1.6457	1.6722	336	7.24
11	OS	1.8767	1.5025	2.1577	2.1842	371	11.07
12	OP	1.6853	0.6723	1.3708	1.3859	364	6.9

Water Chemistry 1999 (Figure 5.8)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.868	0.814	0.6771	0.3569		
1	AC00 8A	0.4763	2.4166	0.2708	-0.3616	9	1.59
2	AC00 9A	0.1763	-0.1954	-0.6717	0.9082	71	2.83
3	AC16 0A	-0.2194	-0.1828	-0.8319	1.0085	1	1
4	AD00 9A	0.2262	-0.2259	-0.6953	0.8814	32	1.28
5	AM00 6A	3.3452	-0.5276	0.2607	-0.0088	10	1
6	AU00 3A	-0.2725	-0.2313	-0.9454	0.3004	47	1.86
7	BR01 0A	-0.2287	-0.0332	-0.7905	1.1373	339	4.34
8	BR01 0B	-0.3177	-0.2888	-0.6514	-0.3588	107	2.28
9	BR01 0C	-0.3365	-0.2505	-0.1248	-0.5309	88	5.52
10	BR01 0E	-0.2726	-0.2329	-0.7109	0.2221	89	3.04
11	CM00 4A	-0.2539	-0.2564	-0.6394	0.2601	78	2.88
12	CO00 1B	3.3452	-0.5276	0.2607	-0.0088	32	1
13	CO00 1C	3.3452	-0.5276	0.2607	-0.0088	17	1
14	CO00 9D	3.3452	-0.5276	0.2607	-0.0088	11	1
15	DE00 1A	-0.3561	-0.2402	0.4528	0.9077	27	2.88
16	DE00 2A	-0.4313	-0.3706	0.9515	-0.1219	523	2.78
17	DP00 1A	-0.309	-0.2639	-0.9097	-0.1383	25	1.17
18	DP06 5A	3.2302	-0.5165	0.2254	0.024	31	1.07
19	EC00 1A	-0.2398	-0.3494	-0.2797	-0.818	674	4.14
20	EU00 2A	-0.226	-0.1889	-0.8461	0.9198	50	1.17
21	EU00 9C	-0.2194	-0.1828	-0.8319	1.0085	5	1
22	EU00 9D	-0.2961	-0.2529	-0.9956	-0.0133	38	2.24
23	EU00 9I	-0.2493	-0.2093	-0.7668	0.6635	11	1.75
24	EY01 0A	-0.3235	-0.3365	-0.4813	-0.8714	51	2.35
25	FG00 1U	-0.1889	0.3079	-0.9165	2.4368	6	1.38
26	FR05 7A	-0.5039	-0.3929	1.7934	0.4766	386	1.51
27	FU00 2A	-0.3026	-0.2589	-1.0096	-0.1009	13	1
28	GO00 4A	-0.267	-0.3186	0.15	-0.0302	34	5.12
29	MA00 1B	-0.2868	-0.2729	-0.7073	-0.1209	330	5.21
30	NA00 1P	3.3452	-0.5276	0.2607	-0.0088	17	1
31	NA00 3A	-0.2852	-0.2474	-0.414	0.1847	62	3.88
32	NA00 8C	0.1241	2.709	0.0835	-0.0078	12	1.41
33	NA00 9P	-0.3026	-0.2589	-1.0096	-0.1009	21	1
34	NA00 9S	-0.3105	-0.3557	-0.3291	-1.0207	10	1.47
35	NA26 7A	0.1891	3.2284	0.2767	-0.3825	30	1
36	NA36 5A	3.3452	-0.5276	0.2607	-0.0088	82	1
37	NA75 1A	-0.1352	-0.0759	-0.8144	0.6475	70	2.83
38	NI00 3A	-0.5089	-0.3927	1.852	0.5354	31	1
39	NI00 5S	-0.3333	-0.3989	-0.2034	-1.528	26	1
40	NI00 8A	-0.3589	-0.3699	0.0484	-1.0821	24	2.07
41	NI00 8N	-0.3026	-0.2589	-1.0096	-0.1009	37	1
42	NI00 9A	0.1598	2.3915	0.1753	-0.0137	270	1.75
43	NI00 9S	0.1891	3.2284	0.2767	-0.3825	21	1
44	NI01 1S	3.3452	-0.5276	0.2607	-0.0088	9	1
45	NI01 4A	-0.3821	-0.3222	0.2395	-0.5683	16	1
46	NI01 7A	-0.2037	0.0696	-0.8754	1.7431	21	1.96
47	NI06 5A	3.3452	-0.5276	0.2607	-0.0088	8	1

48	PI00 9S	-0.248	-0.1305	-0.5571	0.1025	92	3.46
49	PS00 1A	3.3452	-0.5276	0.2607	-0.0088	2	1
50	SP01 2S	3.3452	-0.5276	0.2607	-0.0088	75	1
51	SR10 3A	-0.3026	-0.2589	-1.0096	-0.1009	9	1
52	SS00 1C	0.1572	2.9673	0.186	-0.2369	50	1.18
53	ST00 9J	-0.3026	-0.2589	-1.0096	-0.1009	9	1
54	SU02 4B	0.1891	3.2284	0.2767	-0.3825	9	1
55	SV00 9P	0.0017	-0.2802	-0.7849	-0.0397	24	1.71
56	SV02 0C	-0.2766	-0.2351	-0.9541	0.2458	16	1.75
57	UN00 9S	0.1891	3.2284	0.2767	-0.3825	27	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.868	0.814	0.6771	0.3569		
1	PP	0.1888	3.2284	0.2766	-0.3825	359	2.85
2	BS	-0.3616	-0.4077	-0.0348	-1.3838	407	4.2
3	BE	-0.3047	-0.3898	-0.374	-1.674	402	2.13
4	OD	-0.183	0.4061	-0.9334	2.7225	163	2.23
5	OE	-0.3821	-0.3222	0.2396	-0.5683	265	5.34
6	LS	-0.3175	-0.2915	-1.082	-0.231	380	8.21
7	LE	-0.2875	-0.2266	-0.9382	0.0275	385	7.44
8	ON	-0.4926	-0.4525	1.475	-0.0416	426	2.24
9	ME	-0.5285	-0.3214	2.3018	1.2238	357	1.35
10	OJ	3.3455	-0.528	0.2606	-0.0089	336	7.24
11	OS	-0.2044	-0.2812	-0.7773	0.7624	371	11.07
12	OP	-0.2347	-0.0823	-0.8875	1.2594	364	6.9

Environmental Variables

N	NAME	AX1	AX2	AX3	AX4
		0.9999	0.9986	0.9813	0.9571
1	Calcium	0.5069	0.6025	0.3421	0.2257
2	Magnesiu	0.9675	-0.0691	0.2097	0.0737
3	Sodium	0.9679	-0.179	0.1688	0.0242
4	Potassiu	0.9672	-0.1788	0.1721	0.0199
5	Chloride	0.9576	-0.1862	0.2106	0.0359
6	Sulphate	0.719	0.4556	0.4223	0.1814
7	Bicarbon	0.3096	-0.3986	0.0766	0.6254
8	Ph	0.2961	0.1261	0.5779	-0.413
9	Conducti	0.8648	-0.181	0.4426	0.121

New River Lagoon (Figures 5.9 and 5.10)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.5048	0.2908	0.115	0.056		
1	AC00 8A	1.0759	-0.2189	2.1657	1.8686	28	7
2	AC00 9A	-0.4622	3.1573	0.668	1.8313	166	5.95
3	AC13 4A	-0.7413	-0.541	0.5779	-0.3085	26	2.4
4	AD00 9A	3.0478	1.2811	1.8535	0.735	835	10.83
5	AM00 8A	0.646	0.2853	2.3132	0.4103	1	1
6	BR01 0A	0.1744	2.7093	0.1877	1.7177	564	8.08
7	BR01 0B	-0.686	-0.7645	1.1304	-0.1908	337	2.97
8	BR01 0C	0.587	1.3219	1.6977	-0.1487	1237	12.33
9	BR01 0D	0.646	0.2853	2.3132	0.4103	5	1
10	BR01 0E	2.6029	2.001	1.8119	0.7055	1253	13.64
11	CM00 4A	-0.0838	3.0839	1.1335	2.3717	16	5.82
12	CO00 1A	-0.5161	-0.2905	1.6801	-0.8198	2	2
13	CO00 1B	-0.8475	2.6172	0.4846	-0.0867	6	1.38
14	DE00 2A	1.2704	0.4957	-0.3452	-0.4155	641	5.4
15	DP00 1A	-0.2453	-0.1818	1.3292	-0.389	6	2.57
16	DP00 7A	2.6754	0.9553	-0.2603	1.6283	9	4.76
17	DP01 0A	4.3982	1.3349	-3.4057	-4.0495	1	1
18	EC00 1A	1.3286	0.9609	1.2477	1.6602	1561	18.71
19	EU00 2A	3.7031	0.8675	-1.3444	-1.2929	41	3.79
20	EU00 9C	-0.9288	-0.929	0.9508	0.7659	6	1.8
21	EU00 9I	0.646	0.2853	2.3132	0.4103	1	1
22	EU00 9S	-0.4368	-0.3967	0.0174	-0.7099	10	2.38
23	EU01 7A	4.3982	1.3349	-3.4057	-4.0495	1	1
24	EU04 7A	4.0282	0.9613	4.0939	3.0699	7	2.58
25	EY01 0A	2.8971	0.9774	0.2888	-0.033	43	10.45
26	EY01 8A	-0.8093	-0.9175	0.9572	0.0156	14	2.13
27	FA00 1A	4.2986	0.9879	7.8757	5.7516	1	1
28	FG00 1U	-0.4704	3.4151	1.2894	1.6338	90	4.27
29	FR05 7A	4.2986	0.9879	7.8757	5.7516	1	1
30	GO00 4A	2.9582	1.1254	1.9922	1.5465	232	11.28
31	GO02 5H	-0.4617	-0.0184	0.6831	1.7224	92	5.03
32	MA00 1A	2.9637	0.6144	0.1145	0.4662	1	1
33	MA00 1B	2.3482	0.3526	1.2836	1.4918	1405	16.3
34	MA00 2B	3.8815	1.0306	-1.2185	-1.3245	28	3.77
35	NA00 3A	0.7644	0.3826	-0.0756	-0.2277	175	11.96
36	NA00 8C	-0.0279	2.9389	1.4989	2.6251	2	2
37	NA00 9S	-0.4423	-0.525	1.9179	-0.9206	37	1.94
38	NA06 6B	4.1833	1.1995	-1.9268	-2.2824	7	1.81
39	NA10 2A	3.1946	1.0177	-1.199	-1.1111	4	4
40	NA12 3A	-0.16	3.0879	0.8383	1.7575	9	1
41	NA14 4A	-0.4651	-0.4877	1.6003	2.458	28	2.14
42	NA75 1A	-0.2075	0.0282	0.5818	-0.4075	108	6.41
43	NE00 1A	2.546	1.3984	-0.1843	0.8637	7	3.27
44	NI00 8A	3.1791	0.7129	5.6287	3.9382	27	2.14
45	NI00 9A	-0.2928	3.4709	1.5886	1.5248	88	4.4
46	NI01 4A	1.2307	-0.0533	2.2195	0.4999	207	11.19
47	NI01 7A	-0.7234	3.7532	1.0428	1.4726	85	2.24
48	PI00 5A	2.6096	1.9536	-0.1536	-0.0178	1	1

49	PI00 8A	3.3358	1.5949	-2.1379	-2.4044	5	1.92
50	PI00 9S	0.646	0.2853	2.3132	0.4103	2	1
51	SL00 1A	2.9744	1.0638	-1.0414	-0.933	36	3.9
52	SR00 1A	4.2742	1.0096	7.722	5.6111	38	1.05
53	SS00 1C	-0.1176	3.1546	1.5821	2.721	7	2.33
54	SV00 9P	0.646	0.2853	2.3132	0.4103	2	1
55	SY00 1A	2.8013	1.5789	1.0289	0.3059	214	5.13
56	SY00 3A	-0.8234	-0.2464	0.3854	-0.2211	19	1
57	XH00 9X	2.8079	1.1351	0.0935	0.5802	134	11.29
58	XI00 9X	3.8823	1.0622	-0.5185	-0.5554	362	4.27
59	XN00 5X	2.4794	1.0003	1.9535	2.3701	51	4.02
60	XN00 6X	1.9521	1.7284	0.0515	1.7114	10	2.38
61	XS01 4X	2.1456	0.7331	-0.3044	1.6675	8	1.68
62	XS01 5X	3.7622	0.9718	-1.9612	-2.0992	50	2.82
63	XU00 9X	1.9305	0.7896	-0.4684	1.1027	4	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.5048	0.2908	0.115	0.056		
1	OE	1.1643	0.6152	0.7867	0.4036	271	5.58
2	XC	0.915	0.6708	0.86	0.2487	401	5.79
3	XD	0.4697	0.95	1.3383	0.3876	410	4.88
4	XE	0.114	0	1.1534	0.6366	396	4.49
5	XF	0.1896	0.6167	1.0354	0.6144	377	9.46
6	XDP	0.912	1.1477	1.3365	0.4846	327	3.15
7	XP	0	2.7155	1.1413	1.3394	279	7.99
8	XPP	0.8347	1.5523	1.3035	0.832	387	4.9
9	XEP	0.6184	2.0895	0.7952	1.5003	392	4.87
10	XRP	0.6663	1.5616	1.0437	1.1628	381	5.07
11	A	2.404	0.9045	0.7059	0.6225	396	7.82
12	B	2.1117	1.2581	1.4954	1.0491	458	5.39
13	C	1.9328	1.0054	1.3008	1.232	424	5.18
14	D	2.0318	1.4335	1.2935	0.7676	445	7.58
15	F	1.7296	1.1325	0.6193	0.66	419	9
16	G	2.2124	1.2944	1.4805	0.9704	443	6.09
17	H	2.216	1.1457	1.4574	1.0611	442	6.59
18	I	1.3188	0.8733	0.0964	0.0324	403	3.21
19	J	2.9813	0.7833	0	0	396	4.48
20	K	2.1492	1.0653	1.3498	1.0749	436	5.65
21	L	1.8547	1.485	1.5302	0.5454	416	4.75
22	M	2.1687	1.1146	1.488	1.091	417	5.61
23	O	2.3286	1.0946	1.38	0.8766	413	6.49
24	P	2.9385	0.7569	1.6872	1.3019	401	4.74
25	Q	2.3308	1.241	1.5888	0.8623	463	5.56
26	R	2.4509	1.4036	1.6452	0.7185	401	4.41

Epiphyte (Figures 5.11 and 5.12)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7327	0.3048	0.1754	0.091		
27	ST02 1A	-0.7922	2.7189	3.6053	4.4918	46	1
28	SY00 1A	-0.5366	0.0519	-1.1523	0.9877	217	5.26
38	XN00 8X	-0.3141	2.6259	2.0796	2.5558	14	1.81
29	XB01 0B	-0.2289	0.3172	-0.6772	1.0896	549	10.84
25	NI01 7A	-0.2184	0.9383	3.454	2.1091	152	3.24
1	AD00 9A	-0.2108	1.5368	0.6892	2.0062	1510	13.45
10	EU01 7A	-0.1917	3.4994	0.1419	0.3884	29	1.15
24	NI01 4A	-0.1714	0.4848	-0.7344	0.3571	129	6.88
5	CM02 3A	-0.1528	-0.1064	4.0327	2.2651	22	2.14
11	EU04 7A	-0.1518	3.314	-0.2742	-0.7177	12	1.67
6	CY00 4A	-0.1452	2.6295	1.5926	1.7852	27	1.62
43	XU00 8X	-0.1212	3.3805	1.29	2.5168	110	1.54
35	XM00 8X	-0.0752	-0.2021	3.8879	1.8714	31	1.98
31	XH00 9X	-0.0743	2.6385	0.0647	-0.5391	266	9.52
9	EC00 1A	0.0484	0.2328	1.6369	0.7558	2836	20.58
37	XN00 5X	0.077	2.7299	1.849	-0.3135	161	8.81
17	MA00 1B	0.0816	0.4683	1.7684	0.6548	1408	18.12
15	FU00 2A	0.263	-2.1867	0.3181	2.7444	13	1
22	NI00 8N	0.263	-2.1867	0.3181	2.7444	37	1
36	XM00 9A	0.2722	2.7898	1.2283	1.9323	115	1.92
19	NA75 1A	0.306	-2.0652	0.2779	2.6978	25	1.18
30	XB02 0C	0.3135	-0.0427	-0.2647	0.2728	1323	15.46
26	PI00 9S	0.3229	-1.7162	1.1352	-1.5356	32	1
33	XI00 7X	0.3982	0.0306	3.4551	0.0653	17	3.04
12	EY01 0A	0.4932	2.5824	0.9909	-0.9819	185	9.3
18	NA00 3A	0.5222	1.5417	2.2222	0.5306	110	11.2
34	XI00 9X	0.661	0.5413	-1.0362	1.9572	118	5.05
3	BR01 0E	0.6971	-1.9059	0.6088	2.345	47	2.05
4	CM00 4A	0.9418	1.6005	-1.2942	-1.8938	145	2.88
21	NI00 8A	1.1954	-0.6348	1.293	0.1225	30	3.36
23	NI00 9A	1.4232	-0.3082	2.1911	1.8024	265	6.83
16	GO00 4A	1.447	2.1189	-0.0184	1.6744	309	16.62
44	XV00 9X	1.6826	1.3039	1.5029	-0.7718	33	1.65
14	FR06 0A	2.0066	2.3966	-0.088	2.352	61	3.06
2	BR01 0A	2.1602	2.1984	1.2133	2.2519	486	12.82
8	DE00 2A	2.3075	1.5053	1.6599	0.3954	622	4.29
20	NI00 3A	2.5525	1.2183	1.1495	-0.1369	31	1
42	XS01 7X	2.7401	1.45	0.7314	2.0598	11	1.42
40	XO03 2X	2.8351	1.5243	0.4959	2.014	11	1.86
41	XS00 7X	2.8373	1.526	0.4907	2.0129	17	1.84
13	FR05 7A	2.8397	1.2772	0.9492	1.0611	902	3.42
39	XN01 9X	2.8936	1.5682	0.3642	1.9858	12	1.18
32	XI00 6X	2.92	1.5812	0.3254	1.9774	8	1
7	DE00 1A	2.9383	0.9382	1.8578	-0.1601	13	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.7327	0.3048	0.1754	0.091		
1	BE	0.2676	0	1.3931	0.5856	402	2.13
2	LE	0.5873	0.0832	0.8954	1.1795	371	6.98
3	ME	2.6825	1.1802	1.0417	1.0365	357	1.35
4	ON	2.1805	1.338	1.388	0.4768	426	2.24
5	B	0.1226	0.631	0.6731	0.9443	456	5.34
6	C	0.1535	0.6214	1.1014	0.6664	421	5.1
7	D	0.1669	0.6629	0.241	0.9764	442	7.48
8	G	0.1057	0.6495	0.5944	0.8779	435	5.88
9	H	0.1875	0.744	0.7421	0.9497	441	6.56
10	K	0.1521	0.6071	0.9189	0.8098	428	5.45
11	L	0.1173	0.4817	0	0.8148	415	4.73
12	M	0.1478	0.6845	0.817	0.9549	416	5.58
13	O	0.2094	0.6515	0.6522	0.8883	409	6.36
14	Q	0.0791	0.5992	0.4414	0.9573	461	5.51
15	R	0.0944	0.6622	0.1635	0.9741	400	4.39
16	Y	0.4433	1.2889	0.7093	0	402	6.74
17	AA	0.2989	2.1554	1.0881	0.9783	385	8.17
18	AD	0.8504	0.9247	1.56	0.643	420	5.41
19	AE	0.4263	0.3787	1.5733	0.8493	408	2.74
20	AF	0	1.3025	1.4014	1.7633	351	5.33
21	AG	0.2692	0.6323	2.0103	0.9971	424	6.34
22	AI	0.3955	0.7433	1.7867	1.0022	397	7
23	AL	0.1708	0.5145	1.3823	0.8993	428	3.14
24	AM	0.3974	0.4223	1.4145	0.9596	429	4.56
25	AP	0.1247	1.5119	1.0458	1.6291	443	3.71
26	AQ	0.5585	1.7691	0.9694	1.084	526	10.24
27	AS	0.8625	1.0349	0.5864	1.2748	368	8.95
28	AU	0.0925	1.0546	1.0112	1.2029	422	3.04
29	BA	2.5867	1.323	0.8411	1.2026	431	1.7
30	BB	2.0307	1.347	0.9087	1.2675	383	3.82

Plankton (Figures 5.13 and 5.14)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.6919	0.1993	0.1147	0.0343		
21	NA26 7A	-1.1557	1.0424	0.3169	0.6285	30	1
24	NI00 9S	-1.1557	1.0424	0.3169	0.6285	21	1
30	SU02 4B	-1.1557	1.0424	0.3169	0.6285	9	1
31	UN00 9S	-1.1557	1.0424	0.3169	0.6285	27	1
29	SS00 1C	-0.2894	0.9045	0.2659	0.7619	59	1.62
18	NA00 8C	-0.0365	1.091	1.2927	0.4738	14	1.88
23	NI00 9A	0.475	0.9527	0.6057	-0.3945	370	2.88
28	PI00 9S	2.0747	2.1315	0.8255	0.7092	37	1.4
26	NI01 7A	2.106	1.2517	0.0862	2.6429	102	3.11
13	FG00 1U	2.3349	0.5028	-0.1638	2.0748	102	5.13
25	NI01 4A	2.3699	-0.5926	-0.5662	-4.3804	32	3.37
20	NA14 4A	2.3829	-0.6561	-0.1158	-2.5777	23	2.25
1	AC00 9A	2.5285	2.1174	1.6317	0.9437	237	6.38
22	NA75 1A	2.5779	1.48	-0.5959	0.6821	100	5.62
4	BR01 0A	2.6296	1.6854	1.3858	-0.3726	652	7.27
6	BR01 0E	2.7655	1.0454	-0.5369	0.8982	219	5.75
17	NA00 3A	2.9709	0.4633	1.8755	0.0889	55	5.63
19	NA12 3A	2.99	2.0961	7.6117	-0.5699	9	1
15	GO02 5H	3.0863	1.8206	2.9696	0.3663	65	4.22
2	AC16 0A	3.3384	1.8757	-1.9533	1.9322	32	1
5	BR01 0C	3.4515	-0.4569	0.1605	1.049	583	5.22
10	DE00 2A	3.5828	-1.5657	1.2616	-0.7583	24	2.82
9	CO00 1B	3.8433	4.2807	-0.6194	1.4779	30	1.23
11	EC00 1A	3.9575	1.7453	1.2844	-0.1016	604	7.98
8	CO00 1A	4.0271	4.5676	-0.2191	1.3148	24	1
16	MA00 1B	4.5467	-0.1627	0.4355	0.3452	259	6.13
7	CM00 4A	4.6277	2.7069	-0.5034	1.1785	132	3.53
14	GO00 4A	5.0779	2.848	-0.0099	1.0937	20	2.82
3	AD00 9A	5.2551	1.0424	0.3169	0.6285	36	1
32	XB01 0B	5.4655	1.0424	0.3169	0.6285	13	1.55
12	EY01 0A	6.048	1.0424	0.3169	0.6285	23	1.29
33	XH00 9X	6.1312	1.0424	0.3169	0.6285	51	1.08
34	XN00 5X	6.1436	1.0424	0.3169	0.6285	39	1.05
27	PI00 8A	6.1669	1.0424	0.3169	0.6285	28	1
35	XN00 8X	6.1669	1.0424	0.3169	0.6285	11	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.6919	0.1993	0.1147	0.0343		
1	PP	0	0.9776	0.502	0.0579	352	2.74
3	OD	2.252	1.5076	1.04	0	161	2.18
5	XHP	2.3746	0.979	0.6816	0.0452	287	8.17
8	XP	2.4225	1.1121	0.5669	1.0361	279	7.99
2	OP	2.8704	1.53	0.7445	0.3188	352	6.61
10	XEP	2.9007	1.4679	1.2196	0.2145	392	4.87
6	XAP	3.0401	1.3669	0	0.6539	184	7.13
9	XPP	3.1613	0.535	0.4843	0.3596	387	4.9
11	XRP	3.2927	1.1594	0.9546	0.3001	381	5.07
4	XDP	3.5245	0	0.4634	0.5848	327	3.15
7	XBP	3.5263	1.7997	0.6111	0.6707	396	7.25
13	AJ	4.3043	0.6667	0.5942	0.4389	219	5.18
12	Z	5.0122	1.2812	0.4941	0.4366	355	7.04

Sediment (Figures 5.15 and 5.16)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.8185	0.6791	0.297	0.1982		
6	AM00 6A	-0.3826	2.2025	1.37	1.4805	10	1
20	CO00 1C	-0.3826	2.2025	1.37	1.4805	17	1
21	CO00 9D	-0.3826	2.2025	1.37	1.4805	11	1
47	NA00 1P	-0.3826	2.2025	1.37	1.4805	17	1
54	NA36 5A	-0.3826	2.2025	1.37	1.4805	82	1
61	NI01 1S	-0.3826	2.2025	1.37	1.4805	9	1
64	NI06 5A	-0.3826	2.2025	1.37	1.4805	8	1
70	SP01 2S	-0.3826	2.2025	1.37	1.4805	75	1
26	DP06 5A	-0.3462	2.1634	1.4201	1.6136	31	1.07
19	CO00 1B	0.4065	0.7034	3.5496	1.2797	151	2.06
18	CO00 1A	0.5274	0.7601	3.554	1.3767	83	1.9
8	AP00 1A	0.7777	0.1861	4.0731	1.5177	18	1
3	AC03 1A	0.9521	0.5781	3.6777	1.6615	47	1.77
41	GO02 5B	0.9876	3.5242	-0.5866	1.4469	12	1
49	NA00 8C	0.9876	3.5242	-0.5866	1.4469	202	1
43	GP00 9S	1.019	3.4823	-0.5689	1.4219	36	1.12
66	PS00 1A	1.0459	4.9964	2.1475	2.1524	11	1.42
59	NI00 9A	1.2352	1.17	2.5977	1.8068	96	3.45
14	CM00 4A	1.3749	2.3804	-0.1837	1.8098	144	3.91
44	GY00 5A	1.4771	1.6864	2.5869	1.8949	31	1.21
17	CM11 0A	1.5651	2.8601	-0.2933	1.0985	74	1.65
38	FR05 7A	1.6082	4.7017	-0.114	1.6632	63	3.79
60	NI00 9V	1.6621	1.8905	1.2018	1.9293	13	1
69	SP00 9H	1.6621	1.8905	1.2018	1.9293	25	1
73	SS00 1C	1.6819	1.9037	1.1871	1.954	75	1.05
33	EU10 8A	1.6853	1.7355	3.0809	2.4048	40	1.6
2	AC00 9A	1.7916	0.6475	2.5229	1.7737	213	6.21
75	SV00 9P	1.8277	-0.402	0.1476	3.5531	24	1.71
32	EU00 9S	1.8804	0.6064	2.859	0.7966	32	4.74
55	NA75 1A	1.9202	0.4661	2.5788	0.2351	179	8.96
22	CY00 4A	2.2866	2.1236	1.8828	2.4567	14	1.56
24	DP00 1A	2.2904	0.1256	1.499	2.9274	59	2.94
1	AC00 8A	2.4424	1.8018	2.6773	1.4924	104	6.29
42	GO02 5H	2.7827	-0.757	1.8845	0.498	67	3.97
34	EY01 0A	2.9311	1.8762	0.9722	1.6482	309	5.06
37	FG00 1U	2.9479	-0.1766	0.7296	0.9633	22	4.32
4	AC13 4A	3.1123	-0.7938	1.3874	-0.7196	34	3.66
63	NI01 7A	3.209	-0.1338	2.2387	-0.4909	29	2.56
35	EY01 8A	3.2678	-1.0747	1.5766	0.5999	19	3.44
77	SY00 3A	3.3485	-1.3035	1.8314	-3.0379	19	1
11	BR01 0B	3.5161	-0.6182	1.5237	0.7745	595	7.13
62	NI01 4A	3.5593	1.4104	0.8893	0.7482	231	12.5
9	AU00 3A	3.579	0.2599	0.6756	3.2559	73	2.86
53	NA14 4A	3.7801	-2.5642	2.5133	1.6096	14	1
85	XM00 7X	3.8521	5.0806	2.3112	2.2598	11	1
89	XP01 4X	3.8521	5.0806	2.3112	2.2598	18	1
90	XS00 5X	3.8521	5.0806	2.3112	2.2598	122	1
91	XS00 6X	3.8521	5.0806	2.3112	2.2598	9	1

92	XS00 7X	3.8521	5.0806	2.3112	2.2598	11	1
94	XS01 6X	3.8521	5.0806	2.3112	2.2598	10	1
78	XA00 9X	3.9317	5.0612	2.6723	2.2312	89	1.09
27	EC00 1A	3.9325	1.0176	2.2574	0.7904	1217	13
51	NA00 9S	3.9951	-0.3325	0.0562	-0.5046	50	3.2
15	CM00 9M	4.0487	-0.8517	-0.0445	3.925	11	1
29	EU00 5S	4.0487	-0.8517	-0.0445	3.925	1	1
50	NA00 9P	4.0487	-0.8517	-0.0445	3.925	21	1
72	SR10 3A	4.0487	-0.8517	-0.0445	3.925	9	1
74	ST00 9J	4.0487	-0.8517	-0.0445	3.925	9	1
30	EU00 9D	4.0668	-0.6664	0.112	3.8136	24	1.28
5	AD00 9A	4.0848	3.4177	2.5595	2.0444	223	9.67
76	SV02 0C	4.0938	-0.3885	0.53	3.6466	16	1.75
31	EU00 9I	4.2274	0.5118	2.0066	3.0964	11	1.75
65	PI00 9S	4.2538	1.0459	2.555	2.9388	23	1.19
12	BR01 0C	4.2659	1.5137	0.4475	0.3917	614	7.97
40	GO00 4A	4.3342	3.6828	2.5735	1.9344	104	11.3
10	BR01 0A	4.5812	1.6869	1.3595	0.3346	377	13.4
48	NA00 3A	4.6718	1.3217	1.6192	0.3591	267	11.9
13	BR01 0D	4.7583	1.6098	1.2905	0.9206	21	2.74
86	XM00 8X	4.9926	2.0931	2.6763	2.6733	35	1
57	NI00 5S	5.0197	1.8107	0.9087	-0.389	26	1
16	CM02 3A	5.0268	2.1705	2.6933	2.6228	12	1.18
39	FR06 0A	5.0746	3.8557	2.9525	2.2549	10	1.92
87	XN00 5X	5.1122	2.0064	2.5247	1.9241	89	4.06
28	EU00 2A	5.1647	1.4056	1.195	2.8432	116	4.21
68	SL00 1A	5.177	1.3254	1.4404	-0.0541	65	5.17
45	MA00 1B	5.2201	1.3041	0.9842	2.6622	1486	12.1
23	DE00 2A	5.3111	1.8636	0.3691	-0.6516	815	7.11
82	XH00 9X	5.3401	2.1379	1.9095	0.8517	65	6.08
25	DP00 7A	5.3827	2.7643	2.7323	1.4951	43	1.9
67	RH00 1A	5.4684	2.1205	1.568	3.3058	27	1.16
84	XM00 6X	5.5151	2.9635	3.0751	1.3094	9	1.25
56	NE00 1A	5.5167	2.6824	2.3427	0.3234	28	1.72
58	NI00 8A	5.6268	2.0725	-0.0739	0.7984	29	2.47
52	NA06 6B	5.8358	2.5833	1.8363	1.2221	17	3.48
93	XS01 5X	5.903	2.1979	-0.1141	0.5088	67	3.82
81	XF00 9X	5.9308	3.5577	3.5704	1.3949	42	1.9
95	XU00 8X	6.0269	3.2322	3.3662	2.8468	110	2.49
88	XN00 9X	6.055	2.0147	2.9848	3.2292	12	1.18
83	XI00 9X	6.0621	2.3995	-0.225	0.8406	361	4.18
71	SR00 1A	6.1358	2.1696	-0.2749	1.6151	38	1.05
7	AN00 9A	6.1761	3.3775	3.8085	1.5867	12	1.18
46	MA00 2B	6.2321	3.2928	3.3369	1.1058	56	2.32
79	XF00 7X	6.284	3.4521	3.8851	1.4026	16	1
80	XF00 8X	6.284	3.4521	3.8851	1.4026	14	1

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.8185	0.6791	0.297	0.1982		
12	OJ	0	1.9404	1.7414	1.4953	336	7.28
14	XI	1.3282	2.989	0	1.4277	403	3.56

13	XB	1.3894	0.8123	2.8942	1.2921	364	7.81
15	XH	2.0521	1.1558	1.8241	1.5511	378	11.6
16	XA	2.4668	1.8942	1.0106	1.3853	394	6.23
17	XG	3.0725	0.7752	1.8912	1.3518	385	10.2
4	XF	3.5812	0.3941	1.6065	0.685	375	9.36
3	XE	3.6476	0	1.6213	0.9812	392	4.4
11	AZ	3.7855	4.6228	2.1532	2.0447	356	5.28
2	XD	3.9008	1.0493	1.1151	0.5056	410	4.88
10	AX	3.946	1.3411	1.9101	0.8483	395	3.58
5	LS	3.9646	0.3679	0.8698	2.4306	381	8.34
7	OS	4.2084	1.3046	1.556	1.7646	367	10.8
1	XC	4.4161	1.2443	0.9946	0.5986	401	5.79
6	BS	4.4557	1.3337	1.32	0.4736	417	4.4
9	AH	4.4727	1.4481	1.734	1.2251	436	6.09
8	OE	4.571	1.4724	1.0133	0.4537	270	5.53
27	AN	4.6575	1.6789	1.5189	1.5263	420	6.31
23	F	4.6756	1.7081	1.2356	0.6666	406	8.47
25	V	4.7714	2.0951	1.6605	1.1158	375	14.3
26	AC	4.786	1.5794	1.21	1.584	388	4.93
22	A	4.9104	1.7413	1.1014	1.3172	391	7.63
24	I	4.9439	1.5052	0.8534	0	395	3.09
21	X	5.1667	1.6499	1.4026	2.4599	397	2.4
20	P	5.272	1.8629	0.6856	1.6683	394	4.58
19	AY	5.3879	2.7699	2.6718	1.6791	272	10.9
18	J	5.5078	1.9138	0.6072	1.3338	388	4.3

Additional species codes for fossil/modern data set

MUC001	Achnanthes delicatula var haukiana (Grunow) Lange-Bertalot in Lange Bertalot and Ruppel 1980
MUC003	Achnanthes hungarica (Grunow) Grunow in Cleve and Grunow 1880
AC001A	Achnanthes lanceolata (Brebisson) Grunow in Cleve and Grunow 1880
AC049A	Achnanthes ploenensis Hustedt 1930
AM001A	Amphora ovalis (Kutzing) Kutzing 1844
AM094B	Amphora proteus Greg.
AM9990	Amphora subcapitata (Kisselev) Hustedt 1959
CA006A	Caloneis amphisbaena (Bory) Cleve 1894
XCI001Z	Caloneis incognita Hustdet
CH009X	Chaetoceros sp
XCH001Z	Chiwa Lagoon sp 5
CI004A	Craticula cuspidata Kutz (Mann, 1990)
MUC004	Cyclostephanous dubius (Fricke) Round 1982
CY028A	Cyclotella distinguenda Hustedt 1927
CY003A	Cyclotella meneghiana Kutzing 1844
CY035A	Cyclotella plitviscensis Hustedt 1945
XCT001Z	Cyclotella stelligera var tenuis
CM011A	Cymbella parva (W.Smith) Cleve
DE002B/3A	Denticula elegans varieties
MUC006	Diatoma tenuis Agardh 1812
DP009A	Diploneis elliptica (Kutzing) Cleve 1891
DP001B	Diploneis ovalis variety
EY010A	Encyonema mesianum (Cholnoky) Mann 1990
Ey012A	Encyonema muelleri (Hustedt) Mann 1990
EY016A	Encyonema silesiacum (Bleisch in Rabenhorst) Mann 1990
EP003A	Epithemia argus (Ehrenberg) Kutzing 1844
EP004A	Epithemia turgida (Ehrenberg) Kutzing 1844
EU009D	Eunotia exigua (Brebisson ex Kutzing) Rabenhorst 1864
EU048A	Eunotia naegelii Migula in Thome 1907
EU005S	Eunotia sp
FA001A	Fallacia pygmaea (Kutz) Stickle and Mann 1990
FR005A	Fragilaria virescens Ralfs 1843
MUC008	Gomphonema intricatum var lunata nov. var. Germain 1981
SP009H	Irish Creek Navicula sp
XM005X	Kates Lagoon Cymbella sp
MUC010	Mastogloia muradi Voigt
MUC011	Mastogloia recta Hustedt
MUC012	Navicula bremensis Hustedt 1957
XNB001Z	Navicula brasiliana variety
NA051A	Navicula cari Ehrenberg 1836
NA021A	Navicula cincta (Ehrenberg) Ralfs in Pritchard 1861
NA050A	Navicula clementis Grunow 1882
NA067A	Navicula crucicula (W.Smith) Donkin 1872
NA039A	Navicula festiva Krasske 1925

SP012S	Navicula florinae (dissolved)
XNG001Z	Navicula gaweniensis Gasse 1986
NA418A	Navicula helvetica Brun 1895
NA047A	Navicula protracta (Grunow) Cleve 1894
NA003B	Navicula radiosa variety
XNV008Z	Navicula sp 8
XNS001Z	Navicula subatomoides Hustedt
Unid 17	Neidium sp (L)
XNF001Z	Nitzschia amphibia f.frauenfeldii (Grunow) Lange-Bertalot 1987
XNM001Z	Nitzschia amphibiodes Hustedt 1942
XNM003Z	Nitzschia angustatula Lange-Bertalot 1987
NI023A	Nitzschia scalaris (Ehrenberg) W.Smith 1853
NI011S	Nitzschia sp
NI005S	Nizschia sp
Unid 23	Northern Lagoon species 14
PI170A	Pinnularia braunii (Grunow) Cleve 1895
XPN001Z	Pinnularia sp
PI007A	Pinnularia viridis Hustedt 1930
XPL001Z	Plagiotropis lepidoptera (Pfitzer) Cleve
PS001A	Pseudostaursira brevistriata (Grun. In Van Heurck) Williams and Round 1987
XSC001Z	Small Croc Lagoon sp 15
Unid 24	Small Croc Lagoon species 15 (large variety)
XSS001Z	Small side view (L)
Unid 33	Species A (L)
SS002A	Staurosirella pinnata (Ehrenb) D.M.Williams and Round
ST021A	Stephanodiscus minultus (Kutzing) Cleve and Moller 1878
SR012S	Striatella sp
Unid 1	Aulacoseira sp (L)
Unid 2	Centric sp 15 (L)
Unid 3	Chiwa Lagoon species 20
Unid 4	Cyclotella sp 16 (L)
Unid 5	Cyclotella sp 9 (L)
Unid 6	Gomphonema sp 8 (L)
Unid 7	Mastogloia species small (L)
Unid 8	Mastogloia species small dissolution stage 4 (L)
Unid 9	Navicula sp 16 (L)

Modern/Fossil Data Set (Complete) (figure 5.17)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.4992	0.3915	0.2973	0.2528		
1	AC 001A	1.7785	1.4619	-0.2647	-1.7767	1	1
2	AC 008A	1.7012	1.6926	-0.1539	-1.2711	1280.41	19.07
3	AC 008D	-0.4288	0.0974	-0.7686	-0.2565	12.01	3.01
4	AC 009A	-0.7121	0.6381	0.6529	-0.0041	1345.6	4.34
5	AC 013A	1.7356	0.495	0.1581	-0.7571	81	8.9
6	AC 031A	-0.8008	1.0123	1.3355	-0.0738	141.17	3.52
7	AC 049A	0.5361	-1.7094	0.559	0.3609	1	1
8	AC 134A	-0.6227	0.5827	0.573	-0.0587	102.12	3.97
9	AC 160A	0.0363	0.775	0.4	-0.2122	4	4.01
10	AD 009A	-0.5216	0.0136	-0.6792	-0.1599	5383.4	4.48
11	AM 001A	3.0143	1.0853	0.5764	-2.1605	3	1
12	AM 006A	-1.1089	1.4686	3.6555	0.4376	30.04	3.01
13	AM 008A	-0.9524	1.1796	2.6521	0.3425	9.01	3.53
14	AM 094B	2.3835	1.6477	-0.0642	-0.906	71	7.49
15	AM 099X	1.1107	-1.2724	0.7458	0.1811	2	1
16	AM 9990	3.0143	1.0853	0.5764	-2.1605	5	1
17	AN 009A	0.4669	0.2059	-0.5782	0.0994	68.05	7.35
18	AP 001A	-0.8604	1.0191	1.4805	-0.0331	54.06	3.01
19	AU 003A	-0.7043	0.6603	0.6664	-0.0059	219.26	3.84
20	BR 010A	-0.3276	0.0343	0.0026	-0.0582	19797.41	8.67
21	CA 006A	0.4499	-1.396	0.4617	0.2047	2	2
22	CH 009X	2.5398	2.2431	-0.4063	-1.731	15	2.65
23	CI 004A	-0.4793	-0.0317	-0.5298	-0.1801	15.02	3.37
24	CM 004A	-0.6566	0.5383	0.3379	-0.0307	1271.49	5.65
25	CM 009M	-0.8007	0.6552	0.8177	0.0541	33.04	3.01
26	CM 011A	-0.7701	0.8855	0.8652	0.0924	224.26	3.52
27	CM 023A	-0.3835	-0.1157	-0.5215	-0.0971	153.18	4.38
28	CO 001A	-0.6747	1.0279	1.4318	-0.0565	344.38	4.37
29	CO 001B	-0.8987	1.0319	1.7258	0.0764	537.64	3.81
30	CO 001C	-0.2375	1.4906	2.608	-0.067	70.06	5.36
31	CO 009D	-1.1089	1.4686	3.6555	0.4376	33.04	3.01
32	CY 003A	2.0379	1.6988	-0.2154	-1.8757	4	2.67
33	CY 004A	-0.3638	0.2468	-0.2681	-0.2699	136.15	5.76
34	CY 028A	1.8394	0.3112	0.2151	-0.7487	1762	33.6
35	CY 035A	0.42	-1.3235	0.4195	0.2278	57	6.81
36	DE 001A	2.3076	2.2783	-1.094	6.8958	473.1	5.07
37	DE 002A	0.6773	-1.026	0.4535	0.1317	13721.64	52.04
38	DE 002B	-0.8308	0.7097	0.7467	0.3255	1333.59	3.73
39	DE 003A	2.0409	1.6731	-0.3158	-1.496	2	1
40	DP 001A	-0.3406	0.4552	0.8322	-0.0345	224.21	6.09
41	DP 001B	0.2138	-1.0619	-0.0557	0.2384	1	1
42	DP 007A	-0.2435	0.0744	-0.5927	-0.1635	222.24	5.03
43	DP 009A	1.7115	0.6267	-0.023	0.9695	3	3
44	DP 010A	-0.3186	-0.0847	-0.8287	-0.1243	30.03	4.14
45	DP 061A	-0.5691	0.1073	-1.1838	-0.0496	33.04	3.56
46	DP 065A	-1.0968	1.4389	3.5541	0.4282	93.11	3.07
47	EC 001A	-0.2397	-0.1374	-0.1233	-0.0784	18745	9.49
48	EP 003A	2.1628	1.1575	-0.0862	-0.7546	3	3

49	EP 004A	1.0404	-2.3492	1.1901	0.5223	1	1
50	EU 002A	-0.5295	0.1702	-0.1847	-0.0043	381.45	5.24
51	EU 005S	-0.8007	0.6552	0.8177	0.0541	3	3.01
52	EU 009C	-0.6193	0.6619	0.5665	-0.0824	81.1	3.8
53	EU 009D	-0.788	0.6238	0.7367	0.052	114.14	3.69
54	EU 009I	-0.738	0.5717	0.5796	0.1289	33.04	3.51
55	EU 009S	0.6805	0.9813	0.3921	-0.6782	188.11	13.14
56	EU 017A	-0.5515	0.0128	-0.8691	-0.2045	90.11	3.2
57	EU 047A	-0.4893	0.0132	-0.7902	-0.162	75.09	4.11
58	EU 048A	0.7852	-1.3713	0.6266	0.2414	1	1
59	EU 108A	-0.6451	0.81	0.8147	-0.1385	120.14	3.44
60	EU 999X	1.1107	-1.2724	0.7458	0.1811	2	1
61	EY 010A	-0.3655	0.2983	-0.1234	-0.139	1712.88	6.44
62	EY 012A	0.6174	-1.3909	0.4907	0.2601	273	30.63
63	EY 016A	-0.7396	0.6285	0.5987	0.034	198.24	3.75
64	EY 018A	-0.612	0.5745	0.5433	-0.0618	57.07	3.94
65	FA 001A	-0.7879	0.824	1.5901	0.1218	45.05	4.62
66	FG 001U	-0.6626	0.5563	0.5383	-0.0425	355.41	4.36
67	FR 001A	2.4683	1.9751	-0.3209	-1.8172	20	5.13
68	FR 002A	2.3956	2.0492	-0.3677	-1.7906	58	7.28
69	FR 005A	1.0928	-2.1918	1.0756	0.5205	1	1
70	FR 057A	-0.8389	0.5749	-0.4264	0.6227	2900.45	5.12
71	FR 060A	-0.5073	0.0133	-0.7454	-0.1092	213.25	4.01
72	FU 002A	-0.7804	0.5932	0.6634	0.0289	39.05	3.01
73	G0 OO4A	-0.2058	0.27	-0.4952	-0.265	1514.56	6.54
74	GO 014A	0.8242	-1.5903	0.695	0.3593	24	7.38
75	GO 025B	-1.0279	1.1357	1.5819	0.2653	36.04	3.01
76	GO 025H	-0.6699	0.574	0.5776	-0.0519	387.46	4.24
77	GP 009S	-1.0095	1.1187	1.5271	0.2518	108.13	3.12
78	GY 005A	-0.6916	0.9998	1.0701	-0.1482	93.11	3.19
79	MA 001A	0.8665	-0.9768	0.3903	0.2152	1457.1	54.89
80	MA 001B	0.1394	-0.2507	-0.1742	0.0759	17748.36	14.19
81	MA 001C	-0.5945	0.3758	0.6917	0.1058	283.3	4.73
82	MA 001D	-0.7544	0.553	0.6258	0.0439	189.23	3.97
83	MA 002B	-0.443	-0.0353	-0.8168	-0.1179	282.34	4.01
84	MA 002C	1.4717	-0.3983	0.2855	0.6429	667	29.73
85	MU C001	0.4557	-1.4456	0.532	0.2173	1	1
86	MU C003	0.9324	-1.5583	0.578	0.5261	3	1.8
87	MU C004	0.6423	-1.7357	0.6348	0.3615	75	4.8
88	MU C005	0.748	-1.6788	0.8754	0.2553	1	1
89	MU C006	0.2138	-1.0619	-0.0557	0.2384	1	1
90	MU C007	0.7862	-1.4958	0.6976	0.2273	14	8.91
91	MU C008	1.0404	-2.3492	1.1901	0.5223	1	1
92	MU C009	0.9413	-2.0801	1.0399	0.4152	6	1.8
93	MU C010	0.9901	-2.0264	0.9511	0.5718	59	2.19
94	MU C011	0.9684	-2.2578	1.1	0.4992	7	1.32
95	MU C012	0.7882	-2.0293	0.8745	0.4416	2	2
96	MU C013	1.0404	-2.3492	1.1901	0.5223	1	1
97	NA 001P	-1.1089	1.4686	3.6555	0.4376	51.06	3.01
98	NA 003A	0.1356	-0.5813	0.1654	0.0382	2912.59	23.24
99	NA 003B	2.002	1.4379	-0.193	-1.5474	40	8.79
100	NA 008C	-1.0155	1.1173	1.5366	0.2444	648.77	3.14
101	NA 009P	-0.8007	0.6552	0.8177	0.0541	63.08	3.01
102	NA 009S	-0.6111	0.4986	0.4679	-0.0108	150.18	3.9

103	NA 010A	2.5373	2.1895	-0.2922	-2.1083	9	3.52
104	NA 014A	2.1166	-0.0041	0.4946	-0.6969	137	11.21
105	NA 021A	0.5361	-1.7094	0.559	0.3609	3	1
106	NA 022A	0.5361	-1.7094	0.559	0.3609	8	1
107	NA 039A	0.5361	-1.7094	0.559	0.3609	1	1
108	NA 047A	0.1308	-1.0483	0.4001	0.1075	1	1
109	NA 050A	0.5939	-1.5765	0.6207	0.2998	35	6.35
110	NA 051A	0.9396	-2.2212	1.0639	0.49	5	1.47
111	NA 056A	2.0485	0.7332	0.0251	0.3027	59	18.61
112	NA 058A	-0.4288	0.0974	-0.7686	-0.2565	12.01	3.01
113	NA 066B	-0.092	0.1962	-0.6854	-0.3449	61.06	4.97
114	NA 067A	2.7136	1.9025	-0.1187	-1.9364	25	4.31
115	NA 102A	0.0076	-0.0793	-0.3934	0.0486	80.07	6.95
116	NA 123A	-0.7146	0.4689	0.4843	-0.0263	27.03	3.01
117	NA 144A	-0.6551	0.5085	0.4646	-0.0251	108.13	3.87
118	NA 267A	-0.8954	0.9985	1.0517	-0.1029	90.11	3.01
119	NA 365A	-1.1089	1.4686	3.6555	0.4376	246.29	3.01
120	NA 418A	1.0404	-2.3492	1.1901	0.5223	1	1
121	NA 650A	0.7936	-1.1391	0.5725	0.144	20	6.67
122	NA 751A	-0.4511	0.2154	0.6071	0.0281	1089.05	7.06
123	NE 001A	-0.3816	-0.0077	-0.6672	-0.2042	85.1	3.58
124	NI 003A	-0.953	0.8501	0.855	0.4665	93.11	3.01
125	NI 005S	-0.6569	0.3799	0.5462	0.0825	78.09	3.01
126	NI 008A	-0.0798	0.3847	-0.21	-0.2127	212.21	7.53
127	NI 008N	-0.7804	0.5932	0.6634	0.0289	111.13	3.01
128	NI 009A	-0.6644	0.5251	0.376	-0.0658	2250.66	5.55
129	NI 009S	-0.8954	0.9985	1.0517	-0.1029	63.08	3.01
130	NI 009V	-0.6735	0.9977	1.0261	-0.1606	39.05	3.01
131	NI 011S	-1.1089	1.4686	3.6555	0.4376	27.03	3.01
132	NI 014A	1.7156	1.2619	-0.2268	0.0322	4925.39	36.06
133	NI 017A	-0.5947	0.2149	-0.1203	-0.0789	847.01	5.46
134	NI 023A	2.3519	1.4597	0.064	-1.2841	1	1
135	NI 065A	-1.1089	1.4686	3.6555	0.4376	24.03	3.01
136	PI 005A	0.59	0.4983	-0.5435	-0.0159	60.04	9.29
137	PI 007A	0.9064	-1.9214	0.815	0.4424	3	1.8
138	PI 008A	-0.0518	-0.212	-0.3962	-0.1169	152.14	6.13
139	PI 009S	-0.6946	0.4854	0.4583	0.1014	276.33	3.94
140	PI 170A	3.0143	1.0853	0.5764	-2.1605	12	1
141	PS 001A	-0.8816	0.4782	-1.1518	0.1757	33.04	3.75
142	RH 001A	-0.3617	-0.1697	-0.519	-0.0738	105.13	3.56
143	SL 001A	-0.0029	-0.628	-0.0936	-0.002	361.26	10.58
144	SP 009H	-0.6735	0.9977	1.0261	-0.1606	75.09	3.01
145	SP 012S	-1.1089	1.4686	3.6555	0.4376	225.27	3.01
146	SR 001A	-0.399	0.0258	-0.7778	-0.1448	132.16	3.32
147	SR 103A	-0.8007	0.6552	0.8177	0.0541	27.03	3.01
148	SS 001C	-0.3812	1.0464	0.8891	-0.2057	448.48	4.57
149	SS 002A	-0.6117	0.1161	-1.405	-0.0958	21.03	3.48
150	ST 009J	-0.8007	0.6552	0.8177	0.0541	27.03	3.01
151	ST 021A	-0.5918	0.0177	-0.8275	-0.2177	138.16	3.01
152	SU 024B	-0.8954	0.9985	1.0517	-0.1029	27.03	3.01
153	SV 005C	-0.8007	0.6552	0.8177	0.0541	12.01	3.01
154	SV 009P	-0.8074	0.7095	1.0144	0.1018	72.09	3.49
155	SV 020C	-0.78	0.6214	0.7222	0.0824	48.06	3.51
156	SY 001A	-0.5121	-0.0046	-0.6125	-0.1598	711.85	4.18

157	SY 003A	-0.4531	0.623	0.4593	-0.185	61.07	3.39
158	UN 009S	-0.8954	0.9985	1.0517	-0.1029	81.1	3.01
159	U NID1	2.8027	1.6488	0.1039	-2.0119	6	3.6
160	UN ID17	2.2525	0.8857	0.2064	-1.415	8	5.33
161	U NID2	2.201	-0.7226	0.84	-0.1884	1	1
162	UN ID23	3.0143	1.0853	0.5764	-2.1605	1	1
163	UN ID24	2.274	1.8168	-0.3047	-1.2279	2	1
164	U NID3	1.1107	-1.2724	0.7458	0.1811	2	1
165	UN ID33	0.3993	-1.2383	0.4317	0.1659	493	24.14
166	U NID4	3.0143	1.0853	0.5764	-2.1605	5	1
167	U NID5	1.6663	-1.2728	0.9904	-0.3454	1	1
168	U NID6	1.6663	-1.2728	0.9904	-0.3454	1	1
169	U NID7	1.9656	-0.1543	0.4146	0.6607	4	2.67
170	U NID9	2.3894	1.3054	-0.18	0.7021	11	4.17
171	XA 009X	-0.8187	0.2568	-2.117	0.1242	279.33	3.18
172	XC 008X	-0.8405	0.352	-1.5235	0.369	27.03	3.6
174	XCH 001Z	2.2595	1.7348	-0.1893	-1.7249	74	6.49
175	XCI 001Z	2.0221	1.4441	-0.1618	-1.6893	3	1.8
176	XCP 001Z	1.3685	0.2609	-0.2499	-0.3095	1	1
177	XCT 001Z	2.7313	2.379	-0.3239	-2.2926	3	1
178	XEU 001Z	2.1968	1.6006	-0.2314	-1.5403	113	13.2
179	XF 007X	-0.5239	0.0594	-1.079	-0.1811	48.06	3.01
180	XF 008X	-0.5239	0.0594	-1.079	-0.1811	42.05	3.01
181	XF 009X	-0.4613	0.0107	-0.8265	-0.1171	228.27	4.01
182	XH 009X	-0.4965	-0.0242	-0.659	-0.1616	1168.39	4.36
183	XI 006X	-0.8481	0.4272	-0.9662	0.5701	24.03	3.01
184	XI 007X	-0.4231	-0.1075	-0.4575	-0.0971	63.08	4.05
185	XI 008X	-0.4202	-0.0772	-0.586	-0.1446	18.02	3.61
186	XI 009X	-0.3917	-0.0634	-0.6804	-0.1184	1538.8	4.38
187	XM 005X	-0.5109	-0.0089	-0.3988	-0.1356	18.02	3.01
188	XM 006X	-0.4398	0.0783	-0.7751	-0.2347	30.04	3.39
189	XM 007X	-0.9647	0.3607	-2.5398	0.4576	36	2.62
190	XM 008X	-0.3543	-0.2654	-0.7377	-0.1572	132	2.87
191	XM 009A	-0.513	-0.2145	-1.1818	-0.3001	234.01	2.72
192	XM 009X	-0.3039	-0.1528	-0.9456	-0.2099	26	2.66
193	XN 005X	-0.4104	-0.215	-0.8439	-0.1934	597.03	3.84
194	XN 006X	-0.4285	-0.0556	-0.2677	-0.0573	50.11	2.41
195	XN 008X	-0.5359	-0.1255	-1.1117	-0.2862	50	2.93
196	XN 009X	-0.5627	0.2136	-0.1949	-0.0376	320.05	1.19
197	XN 019X	-0.7746	0.344	-0.9919	0.3263	63.11	2.94
198	XNA 002Z	0.5123	-1.2746	0.5398	0.2381	337.21	16.14
199	XNB 001Z	-0.4281	0.3246	-0.1311	-0.076	786.66	1.12
200	XND 001Z	-0.1361	0.4203	-0.1334	-0.2281	16.05	1.45
201	XNF 001Z	-0.5781	0.2474	-0.1208	-0.0352	392.39	1.01
202	XNG 001Z	1.3885	-1.2726	0.8681	-0.0822	2	2
203	XNM 001Z	0.2494	0.5998	-0.1024	-0.5669	18.04	2.09
204	XNM 003Z	-0.5136	0.2255	-0.0988	-0.0375	39.14	1.06
205	XNS 001Z	3.0143	1.0853	0.5764	-2.1605	1	1
206	XNV 008Z	1.7652	1.7022	-0.3242	-1.4701	45.04	5.19
207	XO 032X	-0.6945	0.2849	-0.754	0.1466	109.26	2.07
208	XO 037X	-0.6368	0.2636	-0.4701	0.0288	87.27	1.34
209	XP 014X	-0.8806	0.2596	-2.6406	0.1478	45.03	2.78
210	XPL 001Z	2.8496	2.4255	-0.7274	3.065	7	2.33
211	XPN 001Z	2.1193	1.6533	-0.2681	-1.4469	141	10.5

212	XS 005X	-0.8284	0.2629	-2.1461	0.1354	387.46	3.12
213	XS 006X	-0.82	0.272	-1.9691	0.1738	33.04	3.36
214	XS 007X	-0.8078	0.3211	-1.4047	0.331	84.1	3.83
215	XS 014X	-0.3686	-0.143	-0.4648	-0.1187	24.03	3.48
216	XS 015X	-0.4047	-0.0608	-0.6885	-0.1487	216.26	4.05
217	XS 016X	-0.8327	0.2734	-2.1061	0.1587	33.04	3.18
218	XS 017X	-0.7435	0.2719	-1.0726	0.2892	42.05	3.64
219	XS 026X	-0.4421	-0.0661	-0.6475	-0.1258	21.03	3.27
220	XSC 015Z	2.7008	1.353	0.2007	-1.3864	247	4.59
221	XSS 001Z	2.3968	1.8691	-0.2997	-1.6661	255	13.21
222	XU 001X	-0.4919	-0.0639	-0.4701	-0.161	18.02	3.01
223	XU 008X	-0.5069	0.0028	-0.8687	-0.1539	666.79	4
224	XU 009X	-0.4294	-0.0487	-0.602	-0.1722	27.03	3.91
225	XV 009X	-0.5866	0.0383	-0.7864	-0.1342	105.13	3.55
226	XY 009X	-0.8481	0.4272	-0.9662	0.5701	18.02	3.01

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.4992	0.3915	0.2973	0.2528		
1	A	-0.1018	-0.3167	-0.7929	-0.1438	396	7.44
2	B	-0.5927	-0.0925	-0.8246	-0.3537	458	4.52
3	C	-0.3253	-0.3318	-0.646	-0.1702	424	4.7
4	D	-0.6327	-0.1056	-0.8633	-0.3641	445	4.65
5	F	0.0023	-0.6027	-0.2336	-0.1799	419	6.47
6	G	-0.5776	-0.1112	-0.8148	-0.2964	443	4.57
7	H	-0.4594	-0.1217	-0.8675	-0.2966	442	5.58
8	I	0.5555	-1.5482	0.6147	0.1824	403	3
9	J	-0.1905	-0.4695	-1.2122	-0.1417	396	4.48
10	K	-0.3845	-0.2726	-0.7081	-0.205	436	5.1
11	L	-0.6323	-0.0054	-0.4592	-0.3128	416	2.46
12	M	-0.4641	-0.1358	-0.8366	-0.298	417	5
13	O	-0.2386	-0.05	-0.8017	-0.2235	413	6.11
14	P	-0.1073	-0.0187	-1.2936	-0.2316	401	4.73
15	Q	-0.3894	0.1053	-0.8945	-0.3019	463	4.59
16	R	-0.4866	0.2224	-0.9613	-0.3658	401	3.66
17	S	-0.0814	-0.4772	-0.7316	0.025	444	2.83
18	U	-0.0947	-0.4496	-0.7121	-0.0071	446	3.62
19	V	-0.2678	0.1947	-1.2572	-0.5953	403	14.34
20	X	-0.1186	-0.2963	-0.9245	0.045	400	2.43
21	Y	-0.6096	0.2316	-0.4702	-0.1897	403	6.64
22	Z	-0.5559	-0.0463	-0.9781	-0.3447	368	7.52
23	AA	-0.6549	-0.0658	-1.6524	-0.4691	400	8.75
24	AC	0.0591	-0.7235	-0.3507	0.0376	389	4.9
25	AD	-0.0935	-0.7005	0.0476	-0.0731	426	5.3
26	AE	-0.5142	-0.1248	-0.1464	-0.2328	414	2.8
27	AF	-0.7574	-0.0447	-1.434	-0.4797	357	5.26
28	AG	-0.3741	-0.2649	-0.4046	-0.1166	425	6.13
29	AH	-0.2179	-0.4768	-0.6187	-0.198	442	6.17
30	AI	-0.3123	-0.266	-0.5192	-0.1679	409	7.06
31	AJ	-0.4455	-0.2073	-0.7246	-0.2176	225	4.75
32	AL	-0.474	-0.23	-0.5934	-0.2457	429	3.13
33	AM	-0.4563	-0.0554	-0.3205	-0.1735	433	4.51

34	AN	-0.238	-0.328	-0.7772	-0.1515	436	6.13
35	AP	-0.7262	-0.1074	-1.591	-0.5121	446	3.72
36	AQ	-0.5367	-0.3841	-1.4282	-0.4563	528	9.47
37	AS	-0.2394	-0.0342	-0.7257	-0.2613	385	7.24
38	AU	-0.7884	-0.085	-1.4053	-0.4821	424	3.05
39	AX	-0.4572	-0.29	-0.3603	-0.3087	406	3.77
40	AY	-0.5535	0.0804	-2.19	-0.3692	287	11.87
41	AZ	-1.4761	0.6772	-5.6171	0.5286	384	6.05
42	BA	-1.5269	1.185	-1.8503	1.8869	464	1.96
43	BB	-1.0554	0.629	-1.0921	1.0274	396	3.61
44	5L	1.1108	-1.2724	0.7458	0.1812	401	3.23
45	46L	1.9408	-1.4603	1.1434	-0.1223	435	2.28
46	51L	2.2009	-0.7226	0.8401	-0.1884	401	3.62
47	56L	2.0409	-0.8927	0.9367	-0.7072	424	3.17
48	61L	1.6663	-1.2728	0.9905	-0.3454	420	3.1
49	67L	3.0144	1.0853	0.5766	-2.162	429	7.9
50	71L	1.3382	-2.0673	1.2587	0.3123	406	1.5
51	76L	2.352	1.4597	0.0641	-1.2842	422	8.06
52	81L	1.8154	1.1598	-0.1766	-1.0743	437	8.66
53	86L	2.279	2.0869	-0.2099	-2.3256	401	9.63
54	91L	1.7785	1.4619	-0.2644	-1.7762	412	10.42
55	96L	3.0375	2.5258	-0.293	-2.4282	433	6.53
56	101L	2.7314	2.3791	-0.3238	-2.2924	406	8.1
57	106L	2.5093	1.4086	0.0441	-1.5145	400	9.36
58	111L	1.3686	0.2609	-0.2497	-0.3098	430	3.84
59	116L	2.2741	1.8168	-0.3046	-1.2277	426	6.76
60	121L	2.2739	2.0486	-0.2679	-1.5458	410	6.88
61	126L	2.0409	1.6731	-0.3157	-1.4958	402	8.37
62	132L	2.6009	2.2173	-0.365	-1.9751	408	6.97
63	139L	3.1817	2.7706	-0.3514	-2.5238	404	5.15
64	144L	2.6475	2.7087	-0.5504	-2.3539	447	5.86
65	149L	2.8411	2.5429	-0.5047	-1.3311	418	3.63
66	154L	1.3905	1.0272	-0.3105	-1.2227	417	9.15
67	159L	1.9661	1.5465	-0.4248	-1.3344	411	7.28
68	164L	2.0065	0.746	-0.1896	-0.8861	398	4.37
69	168L	1.6917	0.537	-0.154	-0.8902	415	4.16
70	189L	1.311	-0.8929	0.3044	0.3707	411	3.84
71	194L	2.5867	1.3296	-0.1697	0.2513	279	2.66
72	199L	1.9624	-0.1981	0.3645	0.2977	353	3.39
73	204L	1.3094	-0.6723	0.189	0.1042	451	3.73
74	209L	1.9828	-0.2999	0.5334	0.0508	415	3.28
75	215L	2.0813	0.3887	0.3183	-0.2929	427	5
76	219L	2.5897	2.1453	0.0626	-0.424	280	3.99
77	228L	2.8023	2.1699	-0.5614	0.2942	267	1.89
78	238L	3.3803	3.2928	-1.7454	11.1812	401	3.45
79	248L	1.6598	-0.8449	0.6499	0.1612	412	2.86
80	253L	2.6494	2.0618	-0.4162	-0.1209	303	3.22
81	263L	2.0606	-0.0806	0.345	1.3874	217	3.79
82	269L	3.6516	3.71	-1.5209	8.064	242	2.15
83	289L	2.2386	1.8488	-1.3191	7.1507	389	3.1
84	294L	2.0791	1.0779	-0.6439	3.0725	322	3.94
85	10H	1.0928	-2.1918	1.0756	0.5204	315	2.53
86	90H	1.3255	-1.7599	1.0332	0.7559	400	3.49
87	113H	0.9269	-1.7459	0.8451	0.3875	400	2.99

88	123H	1.0403	-2.3492	1.1901	0.5223	437	3.2
89	132H	0.8803	-1.6263	0.806	0.1956	437	3.24
90	143H	0.7851	-1.3713	0.6267	0.2412	425	5
91	203H	1.2044	-1.9126	1.0326	0.5263	411	2.74
92	270H	1.2676	-2.3489	1.2385	0.7289	400	2.69
93	290H	0.672	-1.3087	0.4272	0.0399	419	5.18
94	310H	0.454	-1.1198	0.1913	0.1416	494	4.13
95	338.5H	0.536	-1.7094	0.559	0.3611	402	5.96
96	358.5H	1.0425	-1.4372	0.4795	0.6251	446	4.72
97	378.5H	0.6332	-1.506	0.6003	0.228	396	4.54
98	398.5H	0.6763	-1.6661	0.6399	0.3021	401	4.18
99	418.5H	0.8237	-1.4276	0.5933	0.0971	405	5.23
100	420H	0.5086	-1.3386	0.2987	0.2713	390	3.96
101	440H	0.5752	-1.375	0.471	0.2146	399	4.27
102	460H	0.3499	-1.122	0.15	0.2092	442	4.29
103	480H	0.709	-1.5798	0.803	0.1679	400	3.53
104	500H	0.7431	-1.5418	0.7396	0.2009	396	5.32
105	524H	0.7118	-1.8005	0.775	0.3275	400	3.73
106	544H	0.4557	-1.4456	0.532	0.2173	409	5.39
107	564H	0.5944	-1.3408	0.3595	0.3289	432	5.63
108	584H	0.8553	-1.5125	0.5063	0.371	407	4.53
109	604H	0.3262	-0.9493	0.0993	0.1999	396	4.72
110	630H	0.5335	-1.3805	0.2939	0.286	435	4.31
111	650H	0.1478	-0.9226	0.1365	-0.038	416	3.46
112	670H	0.2899	-0.7574	-0.1817	0.1069	459	2.68
113	690H	0.1058	-0.7618	-0.0614	0.1491	397	3.66
114	710H	0.668	-1.0908	0.594	-0.1347	430	7.01
115	733H	0.4932	-1.3687	0.5771	0.2657	398	5.05
116	753H	0.4811	-1.4275	0.7975	0.2574	450	4.5
117	773H	0.453	-1.378	0.5264	0.249	440	5.86
118	793H	0.4583	-1.3282	0.4902	0.1344	396	6.61
119	801.5H	0.574	-1.6345	0.8328	0.2285	410	3.22
120	821.5H	0.3971	-1.2632	0.3741	0.2067	434	5.38
121	841.5H	0.5443	-1.3265	0.6011	0.2071	420	4.9
122	861.5H	0.4099	-1.2678	0.775	0.113	391	3.83
123	881.5H	0.2081	-1.106	0.4893	0.0272	404	5.76
124	920H	0.4955	-1.0364	0.1284	0.0793	470	3.99
125	931.5H	0.2973	-1.0422	0.0664	0.1622	403	3.61
126	941.5H	0.2137	-1.0619	-0.0558	0.2384	405	3.32
127	961.5H	0.8778	-1.7888	0.979	0.2478	406	2.78
128	981.5H	0.1308	-1.0483	0.4	0.1076	406	4.85
129	1001.5H	0.188	-0.9916	0.1484	0.0823	408	5.56
130	1021.5H	0.5796	-1.4654	0.7593	0.188	424	4.31
131	1048H	0.8624	-1.9587	1.0599	0.3857	427	2.35
132	1068H	0.4156	-1.1819	0.4726	0.1787	461	5.51
133	1088H	0.4773	-1.3117	0.5209	0.162	419	4.49
134	1108H	0.8515	-1.58	0.6465	0.3735	422	3.88
135	1128H	0.7479	-1.6788	0.8752	0.2557	398	3.23
136	1340H	0.3991	-1.3069	0.3483	0.2293	400	5.16
137	1345H	0.4451	-1.385	0.5226	0.2422	457	5.22
138	1350H	0.4432	-1.3369	0.4384	0.2193	401	4.34
139	1355H	0.339	-1.1481	0.1968	0.2069	453	4.71
140	1360H	0.1767	-1.0574	0.2617	0.1261	437	5.88
141	1365H	0.4358	-1.348	0.423	0.2063	400	4.51

142	1370H	0.4658	-1.3431	0.512	0.26	422	4.93
143	1375H	0.6429	-1.6102	0.6363	0.3014	433	3.7
144	BS	-0.5755	0.0352	0.5921	0.1402	417	4.99
145	BE	-0.6091	-0.0114	-0.086	-0.1356	402	2.22
146	PP	-1.292	1,8932	2.1102	-0.4177	359	2.85
147	LS	-1.0074	0.862	1.4077	0.0549	385	8.72
148	LE	-0.9464	0.6757	0.9441	-0.0208	385	9
149	OS	-0.8089	0.5372	0.4889	0.3264	377	12.14
150	OP	-0.6332	0.4169	0.4331	0.5069	364	4.88
151	ME	-1.3278	1.4837	-1.2977	3.0897	357	1.35
152	ON	-1.4648	1.4474	1.5194	1.2937	426	2.42
153	OJ	-1.9331	3.3052	9.9313	1.2077	346	7.68
154	OE	-0.5233	0.7007	0.889	0.3493	271	5.72
155	OD	-0.7777	0.4929	0.3755	0.136	163	2.12
156	XA	-0.6975	1.3895	0.745	-0.0388	394	6.45
157	XB	-1.1868	1.9551	3.3986	-0.2072	364	7.62
158	XC	0.0459	-0.6452	0.413	0.0408	401	4.27
159	XD	-0.3515	0.397	0.223	-0.1808	410	2.72
160	XE	-0.4692	0.3908	0.3074	-0.1924	396	4.2
161	XF	-0.5383	0.4572	0.4719	-0.213	377	5.29
162	XG	-0.3242	1.1178	0.7318	-0.6297	400	8.93
163	XH	-0.6254	1.8908	2.0334	-0.5905	379	11.65
164	XI	-1.6897	2.3052	3.7033	0.6889	403	3.56
165	XDP	-0.365	-0.0929	0.1023	-0.08	327	2.81
166	XHP	-0.7083	0.7558	0.6468	-0.1614	287	5.45
167	XBP	-0.9461	0.7695	1.1195	-0.173	396	5.84
168	XP	-1.0568	0.7767	0.7572	-0.1968	279	6.35
169	XPP	-0.5555	0.2213	0.1728	-0.1863	387	2.17
170	XEP	-0.7487	0.3025	0.406	-0.1869	392	3.2
171	XRP	-0.6517	0.1246	0.2755	-0.1903	381	3.66

New River Lagoon (Figure 5.18)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.3169	0.2328	0.1212	0.1159		
1	AC 001A	1.0639	0.4796	-0.0366	0.0691	3.01	3.02
2	AC 008A	1.2864	0.4965	-0.0261	0.0919	2887.98	4.5
3	AC 009A	-1.0027	1.5623	0.0788	1.9238	499.92	4.18
4	AC 013A	0.7403	0.0566	0.0126	0.0983	243.62	5.2
5	AC 049A	-0.3976	-0.7944	0.0371	-0.0085	3.01	3.01
6	AC 134A	-0.8768	1.3106	-0.1057	1.1438	78.3	3.75
7	AC 160A	1.2247	0.3732	-0.0025	0.1064	3.01	3.02
8	AD 009A	-0.879	1.3148	-0.3419	-0.4829	2535.71	4.37
9	AM 001A	1.2492	0.1685	0.0019	0.1778	9.02	3.02
10	AM 008A	-0.832	1.7124	7.644	-1.0983	3.01	3.02
11	AM 094B	1.2858	0.3713	-0.0002	0.0984	213.58	4.24
12	AM 099X	0.5721	-0.1552	0.046	0.0942	6.02	3.02
13	AM 9990	1.2492	0.1685	0.0019	0.1778	15.04	3.02
14	AN 009A	1.0993	0.1005	0.0039	0.03	69.19	4.32
15	BR 010A	-0.477	0.4035	-0.0389	0.1461	20732.05	6.33
16	CA 006A	-0.3913	-0.6686	0.029	0.0276	6.01	3.61
17	CH 009X	1.3562	0.4915	-0.0277	0.1146	45.12	3.81
18	CM 004A	0.1672	0.8703	-0.0594	0.6771	105.34	5.88
19	CM 011A	-0.2718	-0.9652	0.071	-0.0205	6.01	3.01
20	CM 023A	-0.1724	-0.4213	-0.0089	0.007	18.04	4.4
21	CO 001A	1.0421	0.495	-0.0268	0.1795	75.21	4.63
22	CO 001B	-0.9545	1.5589	-0.0783	1.9166	18.07	3.33
23	CO 001C	1.1613	0.4093	-0.0195	0.083	57.16	4.24
24	CY 003A	1.1593	0.4861	-0.0285	0.1449	12.03	3.81
25	CY 004A	0.6422	-0.0389	0.0048	0.1055	39.1	5.08
26	CY 028A	0.7931	0.0183	0.0061	0.0686	5299.72	5.28
27	CY 035A	-0.3866	-0.6151	0.0105	-0.0123	171.34	4.21
28	DE 001A	1.4709	0.3715	-0.0967	-0.2939	1179.22	3.98
29	DE 002A	-0.0667	-0.4897	0.0354	0.0247	33706.76	5.75
30	DE 002B	-0.832	1.7124	7.644	-1.0983	277.07	3.02
31	DE 003A	1.1423	0.4701	-0.0106	0.0789	6.02	3.02
32	DP 001A	-0.0568	-0.2691	0.3081	0.0748	159.38	5.87
33	DP 001B	-0.3847	-0.6165	-0.0137	-0.1263	3.01	3.01
34	DP 007A	0.324	0.3372	-0.0879	-0.1288	99.29	5.98
35	DP 009A	0.7355	-0.0048	-0.0065	-0.0227	9.02	4.79
36	DP 010A	0.0639	0.1066	-0.1737	-0.722	12.03	5.17
37	EC 001A	-0.3538	-0.0603	-0.0194	0.0213	18118.25	6.01
38	EP 003A	1.1197	0.2736	-0.0033	0.0711	9.02	3.88
39	EP 004A	-0.3334	-0.9763	0.0843	0.047	3.01	3.01
40	EU 002A	-0.824	1.2663	-0.558	-1.9564	123.47	4.01
41	EU 009C	-0.8906	1.344	-0.1206	1.1086	18.07	3.55
42	EU 009I	-0.832	1.7124	7.644	-1.0983	3.01	3.02
43	EU 009S	0.8406	0.3449	-0.0185	0.1723	306.85	5.33
44	EU 017A	-0.8808	1.4029	-0.804	-3.0253	3.01	3.02
45	EU 047A	-0.7917	1.3978	-0.5503	-2.2111	21.08	3.8
46	EU 048A	-0.2933	-0.7051	0.0419	0.0435	3.01	3.01
47	EU 999X	0.5721	-0.1552	0.046	0.0942	6.02	3.02
48	EY 010A	0.5753	0.5351	0.0889	-0.1067	520.55	5.62

49	EY 012A	-0.3398	-0.6894	0.0291	0.0077	820.65	4.45
50	EY 018A	-0.8725	1.2781	-0.117	0.9756	42.16	3.67
51	FA 001A	-0.7525	1.4555	-0.5603	-2.6471	3.01	3.02
52	FG 001U	-0.8921	1.568	-0.039	2.1961	292.1	4.38
53	FR 001A	1.2799	0.3996	-0.0299	0.1017	60.16	4.31
54	FR 002A	1.2852	0.4541	-0.0313	0.1011	174.47	4.3
55	FR 005A	-0.2718	-0.9652	0.071	-0.0205	3.01	3.01
56	FR 057A	-0.533	0.071	-0.1594	-0.7712	9.02	4.29
57	G0 OO4A	0.0372	0.8579	-0.0248	-0.2758	1315.35	5.95
58	GO 014A	-0.3032	-0.7703	0.045	0.0122	72.14	4.23
59	GO 025H	-0.9397	1.3588	-0.096	1.2859	277.07	4.12
60	MA 001A	-0.022	-0.5057	0.022	0.0138	4131.04	5.5
61	MA 001B	-0.0519	-0.1298	-0.0312	-0.1338	26384.86	6.3
62	MA 001C	-0.2509	-0.7886	0.0486	-0.0163	84.17	4.03
63	MA 002B	-0.8362	1.3313	-0.59	-2.0679	84.32	4
64	MA 002C	0.3481	-0.3297	0.0133	-0.0152	2005.67	5.87
65	MU C001	-0.3986	-0.6959	0.0482	0.0495	3.01	3.01
66	MU C003	-0.2638	-0.7731	0.0351	-0.0524	9.02	3.54
67	MU C004	-0.3646	-0.7996	0.0436	-0.0078	225.45	4.09
68	MU C005	-0.3483	-0.7283	0.0567	0.1139	3.01	3.01
69	MU C006	-0.3847	-0.6165	-0.0137	-0.1263	3.01	3.01
70	MU C007	-0.3109	-0.7279	0.0509	0.0515	42.08	4.28
71	MU C008	-0.3334	-0.9763	0.0843	0.047	3.01	3.01
72	MU C009	-0.3346	-0.9019	0.0756	0.054	18.04	3.54
73	MU C010	-0.2988	-0.8614	0.06	-0.0037	177.36	3.68
74	MU C011	-0.3426	-0.9503	0.0776	0.0391	21.04	3.28
75	MU C012	-0.3655	-0.8853	0.0607	0.0192	6.01	3.61
76	MU C013	-0.3334	-0.9763	0.0843	0.047	3.01	3.01
77	NA 003A	-0.2866	-0.3999	0.0924	0.0317	5264.89	5.36
78	NA 003B	1.1131	0.3976	-0.0238	0.0961	120.33	4.28
79	NA 008C	-0.9478	1.3374	-0.1059	1.0934	6.02	3.63
80	NA 009S	-0.8399	1.2397	-0.1143	0.7788	111.43	3.61
81	NA 010A	1.3376	0.5176	-0.0218	0.1543	27.07	3.96
82	NA 014A	0.9789	0.0037	0.0207	0.0861	412.13	4.33
83	NA 021A	-0.3976	-0.7944	0.0371	-0.0085	9.02	3.01
84	NA 022A	-0.3976	-0.7944	0.0371	-0.0085	24.05	3.01
85	NA 039A	-0.3976	-0.7944	0.0371	-0.0085	3.01	3.01
86	NA 047A	-0.502	-0.436	0.0113	0.1802	3.01	3.01
87	NA 050A	-0.369	-0.7174	0.04	0.0333	105.21	4.19
88	NA 051A	-0.3462	-0.9399	0.0749	0.0359	15.03	3.37
89	NA 056A	0.9303	0.0947	-0.0025	0.038	177.47	5.04
90	NA 066B	0.2163	0.8955	-0.3531	-1.2379	42.14	5.22
91	NA 067A	1.3457	0.4084	-0.0142	0.1299	75.21	4.05
92	NA 102A	0.1343	0.0096	-0.0692	-0.2063	72.19	6.25
93	NA 123A	-1.0121	1.4438	-0.0968	1.4754	27.1	3.02
94	NA 144A	-0.8966	1.3088	-0.1175	0.9602	84.32	3.68
95	NA 418A	-0.3334	-0.9763	0.0843	0.047	3.01	3.01
96	NA 650A	-0.1691	-0.5236	0.0393	0.0921	60.13	4.77
97	NA 751A	-0.5522	-0.0113	0.0179	0.371	953.51	5.68
98	NE 001A	-0.7028	0.7017	-0.2645	-0.9332	24.09	4.46
99	NI 008A	0.3098	0.8642	0.9517	-0.8139	186.6	5.59
100	NI 009A	-0.6997	1.519	0.2395	1.8708	313.15	4.76
101	NI 014A	1.1443	0.3847	-0.0008	0.0083	11916.25	4.69
102	NI 017A	-1.1182	1.9684	-0.0269	3.1829	255.98	3.71

103	NI 023A	1.2247	0.3732	-0.0025	0.1064	3.01	3.02
104	PI 005A	1.051	0.2945	-0.0251	0.0295	75.21	4.69
105	PI 007A	-0.291	-0.8832	0.0555	-0.0419	9.02	3.54
106	PI 008A	0.1534	-0.2153	-0.0406	-0.2161	129.33	6.22
107	PI 009S	-0.832	1.7124	7.644	-1.0983	6.02	3.02
108	PI 170A	1.2492	0.1685	0.0019	0.1778	36.1	3.02
109	SL 001A	-0.4418	-0.3362	-0.0472	-0.2033	535.27	5.27
110	SR 001A	-0.7573	1.4599	-0.5571	-2.5917	114.44	3.08
111	SS 001C	1.0982	0.5163	-0.0007	0.2876	168.48	4.19
112	SV 009P	-0.832	1.7124	7.644	-1.0983	6.02	3.02
113	SY 001A	-0.9344	1.3664	-0.3464	-0.3762	644.48	4.13
114	SY 003A	-0.5259	1.2611	-0.0879	1.2184	69.25	3.74
115	U NID1	1.3136	0.3333	-0.0112	0.1483	18.05	3.97
116	UN ID17	1.1125	0.2353	0.0014	0.1397	24.07	4.14
117	U NID2	0.9112	-0.171	0.0436	0.0971	3.01	3.02
118	UN ID23	1.2492	0.1685	0.0019	0.1778	3.01	3.02
119	UN ID24	1.2426	0.4382	-0.0216	0.0417	6.02	3.02
120	U NID3	0.5721	-0.1552	0.046	0.0942	6.02	3.02
121	UN ID33	-0.3962	-0.5987	0.0204	0.0624	1481.98	4.45
122	U NID4	1.2492	0.1685	0.0019	0.1778	15.04	3.02
123	U NID5	0.6886	-0.224	0.0424	0.1321	3.01	3.02
124	U NID6	0.6886	-0.224	0.0424	0.1321	3.01	3.02
125	U NID7	0.9324	-0.0298	0.0462	0.0516	12.03	3.81
126	U NID9	1.2047	0.2977	-0.0009	0.0467	33.09	4.04
127	XCH 001Z	1.2194	0.4449	-0.0214	0.1194	222.61	4.2
128	XCI 001Z	1.1215	0.4214	-0.0289	0.0835	9.02	3.54
129	XCP 001Z	0.8306	0.1239	-0.0443	-0.1144	3.01	3.02
130	XCT 001Z	1.4102	0.5347	-0.0222	0.1733	9.02	3.02
131	XEU 001Z	1.1901	0.4042	-0.0241	0.0872	339.93	4.36
132	XH 009X	-0.8675	1.2077	-0.3106	-0.4531	403.55	4.34
133	XI 009X	-0.7886	1.1939	-0.5329	-1.9593	1174.36	4.38
134	XN 005X	-0.8316	1.0459	-0.2492	-0.3369	153.59	4.03
135	XN 006X	-0.7965	0.8579	-0.1993	-0.3004	30.12	3.75
136	XNA 002Z	-0.3283	-0.7574	0.0444	0.0224	835.68	4.42
137	XNB 001Z	1.3087	0.3513	-0.0193	0.0568	120.33	4.27
138	XND 001Z	1.0593	0.3714	-0.0238	0.0721	9.02	3.02
139	XNF 001Z	0.8529	-0.1887	0.0499	0.1303	3.01	3.02
140	XNG 001Z	0.6303	-0.1896	0.0442	0.1132	6.02	3.62
141	XNM 001Z	0.9536	0.3002	-0.0141	0.1413	18.05	4.4
142	XNM 003Z	0.9112	-0.171	0.0436	0.0971	3.01	3.02
143	XNS 001Z	1.2492	0.1685	0.0019	0.1778	3.01	3.02
144	XNV 008Z	1.3593	0.4688	-0.0343	0.1083	102.28	4.05
145	XPL 001Z	1.4649	0.4499	-0.0341	-0.0404	21.06	3.73
146	XPN 001Z	1.1727	0.4344	-0.0282	0.0866	424.16	4.32
147	XS 014X	-0.7901	0.9976	-0.2519	-0.4523	24.09	3.5
148	XS 015X	-0.8322	1.2599	-0.5983	-2.1294	150.58	3.85
149	XSC 015Z	1.2604	0.2676	-0.0036	0.1263	743.03	4.08
150	XSS 001Z	1.2753	0.426	-0.0259	0.0862	767.1	4.36
151	XU 009X	-0.7789	0.9881	-0.2552	-0.5031	12.05	3.02

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.3169	0.2328	0.1212	0.1159		

1	A	-1.0199	1.5139	-1.2091	-3.7808	396	7.44
2	B	-1.4617	1.9854	-0.8485	-0.7719	458	4.52
3	C	-1.1249	1.008	-0.5629	-0.4996	424	4.7
4	D	-1.7283	2.6367	-1.1272	-0.8637	445	4.65
5	F	-1.0292	1.0664	-0.6825	-1.3288	419	6.47
6	G	-1.5229	2.1214	-0.9375	-0.8567	443	4.57
7	H	-1.2426	1.9068	-0.8276	-1.0324	442	5.58
8	I	-0.7404	-0.5617	-0.1422	-0.4857	403	3
9	J	-1.3363	2.3158	-2.3322	-8.9247	396	4.48
10	K	-1.202	1.3546	-0.7221	-0.9339	436	5.1
11	L	-1.5701	2.2002	-0.6823	0.1486	416	2.46
12	M	-1.251	1.7419	-0.7949	-1.0022	417	5
13	O	-1.0563	1.8557	-0.9415	-1.7097	413	6.11
14	P	-0.9499	2.4742	-1.5993	-7.7858	401	4.73
15	Q	-1.3185	2.3756	-1.0479	-1.4602	463	4.59
16	R	-1.4976	2.9751	-1.2276	-1.448	401	3.66
17	OE	-1.1892	3.248	23.107	-3.1216	271	5.72
18	XC	-0.8767	0.1281	-0.0648	0.8328	401	4.27
19	XD	-1.1395	1.6734	-0.2492	2.0548	410	2.72
20	XE	-1.3498	2.0371	-0.3065	3.0434	396	4.2
21	XF	-1.3963	2.341	-0.2158	4.4888	377	5.29
22	XDP	-1.1821	1.165	-0.1765	1.7049	327	2.81
23	XP	-2.3675	5.0084	0.1872	13.3069	279	6.35
24	XPP	-1.3441	1.7982	-0.2608	2.3283	387	2.17
25	XEP	-1.7314	2.4389	-0.2055	4.6296	392	3.2
26	XRP	-1.5219	1.6083	-0.0987	3.376	381	3.66
27	5L	0.0428	-0.7935	0.1525	0.2224	401	3.23
28	46L	0.6321	-1.3093	0.1953	0.2381	435	2.28
29	51L	1.063	-0.8411	0.1455	0.2313	401	3.62
30	56L	0.8878	-0.8943	0.164	0.3312	424	3.17
31	61L	0.3934	-1.0006	0.1413	0.3366	420	3.1
32	67L	2.0798	0.1804	0.0199	0.4735	429	7.9
33	71L	-0.0764	-1.63	0.2245	0.2558	406	1.5
34	76L	2.0062	0.7959	0.0063	0.2591	422	8.06
35	81L	1.5086	0.7905	-0.0577	0.1562	437	8.66
36	86L	2.103	1.318	-0.0661	0.599	401	9.63
37	91L	1.5223	1.1159	-0.096	0.1473	412	10.4
38	96L	2.8322	1.2304	-0.0521	0.3494	433	6.53
39	101L	2.5639	1.2818	-0.0529	0.4607	406	8.1
40	106L	2.0427	0.5915	-0.0257	0.2775	400	9.36
41	111L	0.8204	0.046	-0.1194	-0.4049	430	3.84
42	116L	2.0598	0.9916	-0.051	0.0647	426	6.76
43	121L	2.178	1.2355	-0.0152	0.32	410	6.88
44	126L	1.7582	1.0875	-0.0179	0.1768	402	8.37
45	132L	2.5612	1.1127	-0.0635	0.2962	408	6.97
46	139L	3.1389	1.2694	-0.0816	0.4202	404	5.15
47	144L	2.6043	1.4257	-0.1158	0.3617	447	5.86
48	149L	2.8774	1.2185	-0.0579	0.1335	418	3.63
49	154L	0.9806	0.7268	-0.1222	0.1221	417	9.15
50	159L	1.7023	0.7865	-0.1186	0.0552	411	7.28
51	164L	1.4843	0.2127	-0.0995	-0.1771	398	4.37
52	168L	1.1369	0.3299	-0.0342	-0.1879	415	4.16
53	189L	0.4647	-0.8921	0.0131	-0.3624	411	3.84

54	194L	2.2324	0.4638	0.0247	-0.0283	279	2.66
55	199L	1.1875	-0.5043	0.0884	-0.0483	353	3.39
56	204L	0.5054	-0.6988	-0.0062	-0.3932	451	3.73
57	209L	1.1518	-0.5302	0.1302	0.1206	415	3.28
58	215L	1.3497	0.1365	0.1173	0.3554	427	5
59	219L	2.7644	1.0171	0.0678	0.2669	280	3.99
60	228L	2.7241	1.0257	-0.0342	-0.105	267	1.89
61	238L	3.2409	1.0125	-0.3515	-1.1382	401	3.45
62	248L	0.6413	-0.8655	0.1223	0.0463	412	2.86
63	253L	2.4634	1.0362	0.0021	0.1825	303	3.22
64	263L	1.2581	-0.4683	0.1858	-0.0125	217	3.79
65	269L	3.71	1.4594	-0.2375	-0.7022	242	2.15
66	289L	1.9636	0.438	-0.3241	-1.1532	389	3.1
67	294L	1.6302	0.1601	-0.1786	-0.6817	322	3.94
68	10H	-0.2826	-1.8837	0.1685	-0.1005	315	2.53
69	90H	-0.0096	-1.6789	0.1715	-0.0879	400	3.49
70	113H	-0.314	-1.3785	0.1336	0.0272	400	2.99
71	123H	-0.4677	-1.9172	0.2091	0.1026	437	3.2
72	132H	-0.3708	-1.2957	0.1138	0.1807	437	3.24
73	143H	-0.3473	-1.1018	0.0804	0.0915	425	5
74	203H	-0.1563	-1.6567	0.1715	0.0235	411	2.74
75	270H	-0.2474	-1.8711	0.1946	-0.025	400	2.69
76	290H	-0.4297	-1.0799	0.0359	-0.0546	419	5.18
77	310H	-0.4562	-0.8107	-0.0426	-0.2065	494	4.13
78	338.5H	-0.6606	-1.3702	0.0673	-0.0644	402	5.96
79	358.5H	-0.1221	-1.2431	0.0187	-0.3178	446	4.72
80	378.5H	-0.5285	-1.1478	0.0788	0.1117	396	4.54
81	398.5H	-0.5171	-1.257	0.0505	0.0123	401	4.18
82	418.5H	-0.3456	-1.1508	0.0508	0.0081	405	5.23
83	420H	-0.4578	-1.0963	0.0126	-0.2561	390	3.96
84	440H	-0.4835	-1.0639	0.0591	0.0036	399	4.27
85	460H	-0.5544	-0.8368	-0.037	-0.192	442	4.29
86	480H	-0.5253	-1.1286	0.109	0.2912	400	3.53
87	500H	-0.4792	-1.2461	0.1292	0.1653	396	5.32
88	524H	-0.532	-1.4329	0.1445	0.0458	400	3.73
89	544H	-0.664	-1.0743	0.0985	0.1096	409	5.39
90	564H	-0.4856	-1.0625	0.0207	-0.1241	432	5.63
91	584H	-0.2682	-1.2425	0.0354	-0.2311	407	4.53
92	604H	-0.5816	-0.7687	-0.0266	-0.1	396	4.72
93	630H	-0.456	-1.1446	0.0281	-0.294	435	4.31
94	650H	-0.7768	-0.6629	-0.0096	0.1675	416	3.46
95	670H	-0.4079	-0.644	-0.1214	-0.5235	459	2.68
96	690H	-0.6659	-0.3791	-0.1248	-0.1619	397	3.66
97	710H	-0.4773	-0.8747	0.1514	0.3602	430	7.01
98	733H	-0.6508	-0.7719	0.0341	0.2437	398	5.05
99	753H	-0.7373	-0.8536	0.0791	0.4674	450	4.5
100	773H	-0.6829	-0.8465	0.0682	0.1691	440	5.86
101	793H	-0.6592	-0.994	0.1067	0.1734	396	6.61
102	801.5H	-0.6879	-1.0028	0.1107	0.3962	410	3.22
103	821.5H	-0.6323	-0.8925	0.0031	0.0339	434	5.38
104	841.5H	-0.6319	-0.6674	0.0234	0.2999	420	4.9
105	861.5H	-0.7694	-0.6224	0.0797	0.6302	391	3.83
106	881.5H	-0.922	-0.6375	0.0147	0.5469	404	5.76
107	920H	-0.3819	-0.8293	-0.0508	-0.2541	470	3.99

108	931.5H	-0.5423	-0.7933	-0.071	-0.2453	403	3.61
109	941.5H	-0.622	-0.8355	-0.086	-0.4186	405	3.32
110	961.5H	-0.4337	-1.3229	0.19	0.2725	406	2.78
111	981.5H	-0.9749	-0.293	-0.0119	0.5025	406	4.85
112	1001.5H	-0.7518	-0.5517	-0.0609	0.0422	408	5.56
113	1021.5H	-0.6121	-1.0253	0.0992	0.3491	424	4.31
114	1048H	-0.5009	-1.3167	0.1716	0.2875	427	2.35
115	1068H	-0.6481	-0.7072	0.0107	0.2526	461	5.51
116	1088H	-0.6297	-0.792	0.0167	0.214	419	4.49
117	1108H	-0.3092	-1.2344	0.0735	-0.1027	422	3.88
118	1128H	-0.5125	-1.1717	0.126	0.3036	398	3.23
119	1340H	-0.6226	-0.8993	-0.0282	-0.0889	400	5.16
120	1345H	-0.6592	-0.9098	0.0264	0.0178	457	5.22
121	1350H	-0.6008	-0.8067	-0.016	-0.0629	401	4.34
122	1355H	-0.6117	-0.6816	-0.087	-0.3899	453	4.71
123	1360H	-0.7808	-0.4614	-0.0646	0.1236	437	5.88
124	1365H	-0.6359	-0.7665	-0.053	-0.2355	400	4.51
125	1370H	-0.5804	-0.856	0.0345	0.0487	422	4.93
126	1375H	-0.5209	-1.0947	0.045	-0.112	433	3.7

Dominant Data Set (Complete) (Figures 5.19 and 5.20)
Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.506	0.3661	0.2932	0.2002		
1	AC 008A	1.8726	0.4905	-1.527	-0.1968	1048	16.81
2	AD 009A	-0.8467	1.9275	-0.1324	1.4534	1797	18.32
3	BR 010A	-0.4174	0.449	-0.0643	-0.0515	8922	86.4
4	CY 028A	0.9246	-0.3877	-0.6789	0.188	1762	33.6
5	DE 001A	3.0497	1.133	5.095	0.4601	419	4.11
6	DE 002A	-0.1634	-0.8392	0.0757	0.4768	11680	73.23
7	EC 001A	-0.4126	0.2601	-0.0036	-0.3295	9218	93.07
8	MA 001B	-0.0346	-0.0809	0.1835	-0.4921	10824	94.03
9	NA 003A	-0.3214	-0.3197	0.0754	-0.104	2021	73.32
10	NI 014A	1.7162	0.2778	-0.3657	0.129	4144	38.71

Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.506	0.3661	0.2932	0.2002		
1	A	-0.2912	0.4818	0.0935	-0.4732	278	4.28
2	B	-0.9131	1.7129	-0.1012	0.5489	395	3.45
3	C	-0.5638	0.5933	0.1423	-1.1589	357	3.42
4	D	-0.8883	1.5554	-0.1438	0.6797	325	3
5	F	-0.5087	0.2427	-0.0871	0.6217	343	4.43
6	G	-0.8746	1.7216	-0.0815	0.6773	387	3.54
7	H	-0.7757	1.4994	-0.0045	0.3712	368	4.09
8	I	-0.4465	-1.1018	0.1259	1.198	358	2.39
9	J	-0.1176	-0.4386	0.3987	-1.198	182	2.09
10	K	-0.7109	1.1247	0.0639	-0.1858	383	4
11	L	-0.865	1.4269	-0.1852	0.2974	353	1.8
12	M	-0.8097	1.5636	-0.0253	0.4267	367	4
13	O	-0.5686	1.4972	-0.0926	0.7721	362	4.81
14	P	0.1102	0.3469	0.1636	-1.3963	216	2.04
15	Q	-0.6876	1.9945	-0.2078	1.2701	422	3.84
16	R	-0.7773	2.401	-0.3221	2.037	353	2.87
17	S	-0.3699	0.3333	0.356	-1.5988	388	2.19
18	U	-0.3084	0.1149	0.3921	-2.0368	320	1.93
19	V	-0.205	1.4917	-0.5402	0.6503	216	5.99
20	X	-0.1228	0.057	0.4894	-1.9926	290	1.34
21	Y	-0.4855	0.534	0.1043	-1.5023	204	2.72
22	Z	-0.5249	0.4296	0.1863	-1.787	158	2.32
23	AA	-0.5818	0.568	0.1402	-1.5037	142	2.9
24	AC	-0.3619	-0.2156	0.3313	-0.7579	307	3.25
25	AD	-0.5818	-0.2345	0.1183	-0.3374	339	3.56
26	AE	-0.7185	0.583	0.0453	-1.298	327	1.87
27	AF	-1.0837	2.5641	-0.1915	2.1509	260	3.11
28	AG	-0.471	0.1808	0.2347	-1.4389	284	3.36
29	AH	-0.5019	0.195	0.114	-1.0118	317	3.42
30	AI	-0.4872	0.3736	0.116	-0.9633	285	3.79
31	AJ	-0.768	1.3776	0.0237	0.119	206	4

32	AL	-0.7851	1.1554	0.033	-0.4696	390	2.61
33	AM	-0.6127	0.7962	0.1206	-0.9694	341	3.13
34	AN	-0.4749	0.5609	0.1757	-0.7636	330	3.73
35	AP	-1.2642	3.569	-0.3162	5.0333	320	2.01
36	AQ	-0.8572	1.4422	-0.0965	1.8378	301	4.94
37	AS	-0.4411	0.984	-0.2372	0.6292	267	4.04
38	AU	-1.2499	3.0552	-0.2486	3.0461	369	2.34
39	AX	-0.793	0.6939	-0.0392	-0.8761	274	1.9
40	AY	-0.2901	0.9821	0.0016	-0.4375	88	4.25
41	AZ	-0.8193	2.6493	-0.4702	2.4526	42	2.19
42	BA	-0.8931	1.7963	-0.1657	0.8592	44	1.84
43	BB	-0.772	1.0377	-0.0914	0.1393	164	2.24
44	5L	-0.151	-1.1972	0.1049	1.1213	346	2.42
45	46L	0.2393	-1.7678	-0.1257	1.7959	384	1.8
46	51L	0.7361	-1.3162	-0.3161	1.4433	353	2.84
47	56L	0.5378	-1.4683	-0.6267	1.4101	387	2.65
48	61L	0.1937	-1.3812	-0.381	1.3791	387	2.65
49	67L	0.9716	-0.4893	-0.5566	0.3229	222	4.84
50	71L	-0.2087	-1.8495	0.1275	1.9323	389	1.38
51	76L	1.6766	0.0732	-1.293	0.3159	321	4.91
52	81L	1.3198	0.1724	-1.0427	-0.2443	356	5.92
53	86L	1.7971	0.4923	-2.0102	-0.2561	294	5.51
54	91L	1.0563	0.296	-1.0417	-0.4245	274	5.53
55	96L	2.4633	0.407	-2.2027	0.0867	331	4.01
56	101L	2.2594	0.4617	-2.0289	-0.055	293	4.4
57	106L	1.6007	-0.1126	-1.1273	0.1146	282	5
58	111L	0.67	0.0004	-0.1266	-1.3298	332	2.38
59	116L	1.7669	0.3551	-0.9239	-0.3531	312	3.76
60	121L	2.0038	0.4994	-1.6026	-0.3286	328	4.5
61	126L	1.4442	0.3878	-1.1022	-0.3322	304	5.04
62	132L	2.1809	0.4018	-1.8661	-0.197	324	4.53
63	139L	2.7688	0.5371	-2.5436	-0.0458	328	3.46
64	144L	2.2841	0.7962	-2.1235	-0.4132	354	3.81
65	149L	2.6484	0.6171	-1.6704	-0.1178	348	2.54
66	154L	0.58	0.3893	-0.5801	-0.9454	308	5.26
67	159L	1.3196	0.3578	-0.8574	-0.6998	324	4.64
68	164L	1.2143	-0.1573	-0.7297	-0.6986	342	3.27
69	168L	0.9339	-0.1779	-0.6756	-0.6927	374	3.39
70	189L	0.4053	-0.8036	0.1449	-0.2435	333	2.7
71	194L	2.1248	-0.0113	-0.6629	0.5677	256	2.25
72	199L	1.0569	-0.8293	-0.2764	0.889	324	2.87
73	204L	0.423	-0.6189	0.0663	-0.6075	382	2.78
74	209L	0.9686	-0.963	-0.3896	1.212	387	2.86
75	215L	1.1802	-0.4966	-0.6411	0.9417	372	3.83
76	219L	2.4675	0.3367	-0.8188	0.1986	186	1.94
77	228L	2.6832	0.5217	-0.7971	0.1877	247	1.62
78	238L	3.9791	1.6197	7.4278	0.9006	357	2.76
79	248L	0.3722	-1.268	0.014	1.2366	375	2.38
80	253L	2.2296	0.4397	-0.9073	0.2993	253	2.27
81	263L	1.1082	-0.8269	0.584	1.3171	201	3.26
82	269L	3.9956	1.3323	4.3519	1.137	239	2.1
83	289L	2.3688	0.8884	4.7043	-0.446	367	2.77
84	294L	1.9101	0.5112	1.8505	-0.7226	270	2.91
85	10H	-0.2573	-1.6973	0.3551	1.0355	252	1.69

86	90H	-0.226	-1.6179	0.2856	0.9815	276	1.86
87	113H	-0.3292	-1.2885	0.2258	0.7629	360	2.44
88	123H	-0.4144	-1.481	0.2315	1.1469	331	1.91
89	132H	-0.3541	-1.1016	0.0735	0.7107	397	2.69
90	143H	-0.3719	-0.835	0.132	0.2092	362	3.7
91	203H	-0.2787	-1.5851	0.2061	1.1396	340	1.92
92	270H	-0.2929	-1.708	0.3054	1.2273	313	1.71
93	290H	-0.3141	-0.6431	0.0345	-0.185	357	3.85
94	310H	-0.3039	-0.4926	0.2454	-0.7205	464	3.66
95	338.5H	-0.4763	-0.4622	0.2328	-0.5581	304	3.64
96	358.5H	-0.2153	-0.8137	0.3317	-0.5482	321	2.77
97	378.5H	-0.4444	-0.7537	0.1517	0.1429	345	3.54
98	398.5H	-0.4056	-0.9305	0.2218	0.3022	338	3.04
99	418.5H	-0.254	-0.8149	0.0328	0.131	340	3.8
100	420H	-0.3687	-0.6418	0.3226	-0.6134	354	3.29
101	440H	-0.4086	-0.776	0.2103	-0.0408	373	3.74
102	460H	-0.4129	-0.3683	0.289	-0.875	408	3.67
103	480H	-0.4104	-1.0027	0.081	0.7598	362	2.91
104	500H	-0.3674	-0.904	0.0915	0.35	330	3.77
105	524H	-0.4268	-1.0969	0.2269	0.5042	352	2.91
106	544H	-0.4575	-0.7156	0.221	-0.051	361	4.29
107	564H	-0.4077	-0.2596	0.272	-1.0344	311	3.85
108	584H	-0.2497	-0.8954	0.2832	-0.2442	328	3.13
109	604H	-0.4896	-0.0255	0.2029	-1.2232	334	3.49
110	630H	-0.329	-0.6058	0.3348	-0.8087	383	3.39
111	650H	-0.5873	0.0004	0.0551	-0.8118	380	2.91
112	670H	-0.2245	-0.0845	0.3197	-1.8081	420	2.25
113	690H	-0.3978	0.0845	0.3015	-1.4904	354	2.95
114	710H	-0.3804	-0.6349	-0.0192	0.0894	357	4.99
115	733H	-0.4952	-0.4978	0.1588	0.1142	342	3.87
116	753H	-0.5165	-0.7313	0.115	0.6455	372	3.18
117	773H	-0.4682	-0.4932	0.1935	-0.1154	372	4.33
118	793H	-0.4545	-0.5174	0.1295	-0.2491	339	5.01
119	801.5H	-0.5137	-0.8783	0.1023	0.8538	379	2.76
120	821.5H	-0.4237	-0.4639	0.2247	-0.4697	379	4.2
121	841.5H	-0.4421	-0.4875	0.0913	0.2385	355	3.63
122	861.5H	-0.4943	-0.6617	0.0415	0.676	357	3.23
123	881.5H	-0.5888	0.0754	-0.0512	-0.4109	306	3.81
124	920H	-0.2807	-0.4318	0.2099	-0.8985	439	3.51
125	931.5H	-0.4092	-0.3323	0.2943	-0.9793	382	3.26
126	941.5H	-0.3838	-0.0045	0.3491	-1.767	353	2.55
127	961.5H	-0.3549	-1.3582	0.131	1.1442	379	2.43
128	981.5H	-0.6217	0.2241	0.0258	-0.3878	328	3.38
129	1001.5H	-0.4593	-0.0437	0.1609	-0.9072	357	4.4
130	1021.5H	-0.4487	-0.8528	0.1046	0.5528	368	3.29
131	1048H	-0.4157	-1.3471	0.1891	1.2736	402	2.09
132	1068H	-0.4725	-0.4343	0.1407	-0.1221	404	4.36
133	1088H	-0.4878	-0.5768	0.1242	0.1908	381	3.76
134	1108H	-0.2732	-1.0572	0.2693	0.1899	366	2.97
135	1128H	-0.4473	-1.1068	0.1407	0.9261	356	2.62
136	1340H	-0.4233	-0.5069	0.2596	-0.4258	345	3.93
137	1345H	-0.4419	-0.688	0.2326	0.0038	401	4.08
138	1350H	-0.4278	-0.6992	0.2329	0.0261	373	3.77
139	1355H	-0.3922	-0.4626	0.2931	-0.6486	411	3.91

140	1360H	-0.5187	-0.1533	0.1624	-0.3972	379	4.52
141	1365H	-0.4476	-0.7107	0.2169	0.1353	367	3.82
142	1370H	-0.4223	-0.7278	0.2391	0.0453	368	3.79
143	1375H	-0.4002	-1.0186	0.2508	0.4254	396	3.12
144	BS	-0.6825	0.2317	0.0467	-0.8139	273	2.64
145	BE	-0.788	0.7068	-0.0181	-1.4189	320	1.44
146	PP	2.695	1.3146	-4.0994	-0.8218	9	1.53
147	LS	-0.6275	0.8488	0.001	-0.8312	138	1.63
148	LE	-0.6471	0.7558	0.0307	-1.1311	164	2.64
149	OS	-0.6236	1.2074	0.4135	0.172	180	4.83
150	OP	-0.5236	0.9275	0.515	-0.6178	235	2.28
151	ME	1.9289	1.1893	6.6609	0.9333	34	3.64
152	ON	-0.6506	0.0023	0.0591	-0.4824	49	2.69
153	OJ	-0.6332	2.5538	-0.6646	2.0399	10	3.57
154	OE	-0.1353	0.3133	-0.1089	-0.5536	141	4.78
155	OD	-0.7008	1.2411	0.099	-0.214	112	1.06
156	XA	1.6704	0.713	-0.7367	-0.2758	61	1.99
157	XB	-0.0315	1.0743	-1.0215	-0.8467	63	2.61
158	XC	-0.505	-0.0762	0.0881	-0.1395	365	3.59
159	XD	-0.4005	1.0055	-0.2776	-0.4228	340	1.91
160	XE	-0.4462	0.8476	-0.1569	-0.822	300	2.5
161	XF	-0.4938	0.8066	-0.0969	-0.8617	250	2.48
162	XG	0.2086	0.9169	-0.8908	-0.8776	219	3.62
163	XH	1.4148	0.8224	-1.4312	-0.7101	62	4.41
164	XI	-0.0437	0.4602	-0.1609	-0.9671	18	3.12
165	XDP	-0.5833	0.6564	-0.0048	-0.7172	296	2.32
166	XHP	-0.3459	0.8829	-0.1968	-0.5586	146	2.35
167	XBP	-0.8003	0.9453	-0.1038	-0.9194	204	2.12
168	XP	-0.7852	0.9976	-0.1241	-0.6801	91	1.82
169	XPP	-0.6647	1.0142	-0.1636	-0.5284	337	1.66
170	XEP	-0.7746	0.9762	-0.1165	-0.6645	289	1.82
171	XRP	-0.7663	0.8416	-0.0824	-0.9114	298	2.33

New River Lagoon Dominant (Figures 5.21 and 5.22)

Species

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.5131	0.332	0.2989	0.1623		
1	AC 008A	1.8099	0.2624	-1.4841	-0.0122	960	14.5
2	AD 009A	-0.691	2.2333	-0.0327	-0.4428	842	11
3	BR 010A	-0.4456	0.7091	-0.0585	-0.3685	6890	61.2
4	CY 028A	0.7245	-0.3697	-0.6345	-0.0039	1762	33.6
5	DE 001A	3.079	0.6139	4.8064	-0.5733	392	3.62
6	DE 002A	-0.3094	-0.7001	0.0779	-0.3392	11210	68.3
7	EC 001A	-0.3858	0.2448	0.0002	0.2632	6024	74.5
8	MA 001B	-0.042	-0.031	0.1673	0.6645	8773	79
9	NA 003A	-0.4028	-0.2353	0.0818	0.0758	1751	60.6
10	NI 014A	1.5899	0.1136	-0.3526	-0.1489	3961	35.6

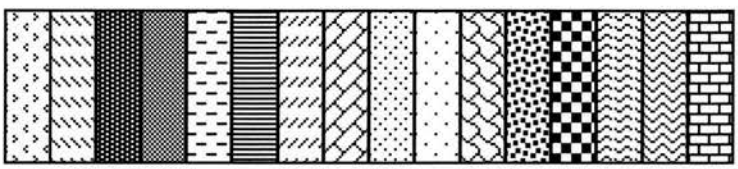
Samples

N	NAME	AX1	AX2	AX3	AX4	WEIGHT	N2
	EIG	0.5131	0.332	0.2989	0.1623		
1	A	-0.3158	0.8234	0.1082	1.0373	278	4.28
2	B	-0.8394	2.3356	-0.0257	-0.2822	395	3.45
3	C	-0.5532	0.9187	0.1435	1.3225	357	3.42
4	D	-0.855	2.2799	-0.0744	-1.0811	325	3
5	F	-0.5822	0.7074	-0.051	-0.8851	343	4.43
6	G	-0.8133	2.4306	-0.0075	-0.4799	387	3.54
7	H	-0.7159	2.0899	0.0577	0.1986	368	4.09
8	I	-0.634	-0.7602	0.1349	-1.5185	358	2.39
9	J	-0.1837	-0.2857	0.3639	2.299	182	2.09
10	K	-0.6702	1.6096	0.1025	0.6311	383	4
11	L	-0.867	2.2435	-0.1342	-1.672	353	1.8
12	M	-0.7404	2.1341	0.0421	0.2052	367	4
13	O	-0.5316	2.072	-0.0201	-0.1703	362	4.81
14	P	0.0871	0.5447	0.1499	2.4783	216	2.04
15	Q	-0.6266	2.7206	-0.1101	-0.8257	422	3.84
16	R	-0.7083	3.2858	-0.1959	-1.7596	353	2.87
17	OE	-0.2182	0.6383	-0.0964	-0.1081	141	4.78
18	XC	-0.602	0.3816	0.0895	-0.5578	365	3.59
19	XD	-0.4525	1.6103	-0.2526	-1.3359	340	1.91
20	XE	-0.4811	1.3792	-0.144	-0.4339	300	2.5
21	XF	-0.5275	1.3504	-0.0879	-0.3437	250	2.48
22	XDP	-0.628	1.2518	-0.001	-0.4945	296	2.32
23	XP	-0.8052	1.6528	-0.1068	-1.0324	91	1.82
24	XPP	-0.7019	1.7107	-0.1451	-1.3215	337	1.66
25	XEP	-0.7979	1.6386	-0.1001	-1.0432	289	1.82
26	XRP	-0.7684	1.2997	-0.067	-0.2489	298	2.33
27	5L	-0.3517	-0.9618	0.1091	-1.1608	346	2.42
28	46L	-0.0446	-1.6531	-0.0998	-1.4226	384	1.8
29	51L	0.4479	-1.2694	-0.2798	-1.1074	353	2.84
30	56L	0.2417	-1.3742	-0.5638	-0.9818	387	2.65
31	61L	-0.0701	-1.1906	-0.336	-1.2268	387	2.65
32	67L	0.7624	-0.4827	-0.5203	-0.0504	222	4.84

33	71L	-0.4617	-1.6565	0.1356	-1.802	389	1.38
34	76L	1.4484	-0.0219	-1.213	-0.4796	321	4.91
35	81L	1.1353	0.1597	-0.981	0.2016	356	5.92
36	86L	1.6112	0.3781	-1.8997	-0.1625	294	5.51
37	91L	0.8943	0.3139	-0.9728	0.3465	274	5.53
38	96L	2.2243	0.1472	-2.083	-0.3566	331	4.01
39	101L	2.0385	0.2433	-1.9177	-0.2192	293	4.4
40	106L	1.37	-0.2156	-1.0561	0.108	282	5
41	111L	0.5641	0.0772	-0.1324	2.1385	332	2.38
42	116L	1.5824	0.2435	-0.8797	0.3987	312	3.76
43	121L	1.8101	0.3478	-1.519	0.1436	328	4.5
44	126L	1.2666	0.349	-1.0362	0.2116	304	5.04
45	132L	1.9704	0.1742	-1.7665	0.0978	324	4.53
46	139L	2.5287	0.2076	-2.4103	-0.2336	328	3.46
47	144L	2.1103	0.5542	-2.0192	-0.0665	354	3.81
48	149L	2.4296	0.3035	-1.5897	-0.037	348	2.54
49	154L	0.4856	0.4749	-0.5487	0.9307	308	5.26
50	159L	1.1757	0.274	-0.8135	0.8704	324	4.64
51	164L	1.0262	-0.1855	-0.6851	1.4916	342	3.27
52	168L	0.755	-0.1082	-0.6321	1.3385	374	3.39
53	189L	0.2492	-0.7435	0.1286	1.0974	333	2.7
54	194L	1.8716	-0.2225	-0.6268	-0.4545	256	2.25
55	199L	0.8158	-0.8639	-0.2575	-0.5567	324	2.87
56	204L	0.2824	-0.5478	0.0538	1.5034	382	2.78
57	209L	0.7088	-0.9745	-0.3577	-1.0375	387	2.86
58	215L	0.9274	-0.4714	-0.5927	-1.05	372	3.83
59	219L	2.2205	0.0678	-0.7758	-0.0552	186	1.94
60	228L	2.4419	0.2136	-0.7611	-0.1626	247	1.62
61	238L	3.8529	0.923	6.8601	-1.3033	357	2.76
62	248L	0.1374	-1.1707	0.0204	-0.9953	375	2.38
63	253L	1.9901	0.2735	-0.8553	-0.5908	253	2.27
64	263L	0.86	-0.8765	0.5452	-1.2643	201	3.26
65	269L	3.7888	0.6956	4.0092	-1.661	239	2.1
66	289L	2.2861	0.5228	4.3376	0.8595	367	2.77
67	294L	1.7924	0.2765	1.6904	1.2649	270	2.91
68	10H	-0.4625	-1.5233	0.339	-0.3982	252	1.69
69	90H	-0.4303	-1.4433	0.2749	-0.3813	276	1.86
70	113H	-0.5054	-1.0858	0.221	-0.4344	360	2.44
71	123H	-0.6013	-1.3288	0.2325	-0.8144	331	1.91
72	132H	-0.5182	-0.9348	0.0835	-0.5124	397	2.69
73	143H	-0.5056	-0.6461	0.1351	0.0445	362	3.7
74	203H	-0.4837	-1.4244	0.2051	-0.6918	340	1.92
75	270H	-0.506	-1.521	0.2959	-0.751	313	1.71
76	290H	-0.427	-0.5176	0.0431	0.5611	357	3.85
77	310H	-0.3908	-0.2977	0.2295	1.2464	464	3.66
78	338.5H	-0.5494	-0.3155	0.2238	0.9223	304	3.64
79	358.5H	-0.3263	-0.6477	0.3075	1.3626	321	2.77
80	378.5H	-0.5651	-0.5636	0.1529	0.0073	345	3.54
81	398.5H	-0.5401	-0.7297	0.2156	-0.0429	338	3.04
82	418.5H	-0.3938	-0.6436	0.0407	0.1981	340	3.8
83	420H	-0.4538	-0.5015	0.3025	1.2637	354	3.29
84	440H	-0.5258	-0.5973	0.205	0.3525	373	3.74
85	460H	-0.4762	-0.1932	0.2708	1.357	408	3.67
86	480H	-0.5741	-0.7632	0.0908	-0.8154	362	2.91

87	500H	-0.5157	-0.7058	0.0992	-0.2087	330	3.77
88	524H	-0.5775	-0.9178	0.2241	-0.2456	352	2.91
89	544H	-0.576	-0.4905	0.2166	0.1818	361	4.29
90	564H	-0.4649	-0.0671	0.2548	1.4683	311	3.85
91	584H	-0.3757	-0.7191	0.2663	0.8984	328	3.13
92	604H	-0.5193	0.1301	0.1929	1.5622	334	3.49
93	630H	-0.4134	-0.4575	0.3129	1.5169	383	3.39
94	650H	-0.6249	0.15	0.0633	0.8132	380	2.91
95	670H	-0.2548	0.0679	0.2895	2.7276	420	2.25
96	690H	-0.4264	0.3587	0.2759	1.8224	354	2.95
97	710H	-0.5216	-0.3932	-0.0002	-0.2086	357	4.99
98	733H	-0.6111	-0.1509	0.157	-0.4018	342	3.87
99	753H	-0.6657	-0.3673	0.1215	-1.1074	372	3.18
100	773H	-0.5836	-0.1518	0.1891	-0.077	372	4.33
101	793H	-0.5623	-0.2885	0.1331	0.2728	339	5.01
102	801.5H	-0.672	-0.5589	0.1113	-1.2313	379	2.76
103	821.5H	-0.5115	-0.2407	0.2144	0.7082	379	4.2
104	841.5H	-0.5746	-0.0845	0.0947	-0.6806	355	3.63
105	861.5H	-0.6483	-0.272	0.0542	-1.2618	357	3.23
106	881.5H	-0.6543	0.3804	-0.0336	-0.1278	306	3.81
107	920H	-0.356	-0.29	0.1964	1.5586	439	3.51
108	931.5H	-0.4619	-0.1865	0.2745	1.5589	382	3.26
109	941.5H	-0.3951	0.1272	0.3202	2.5404	353	2.55
110	961.5H	-0.56	-1.099	0.1391	-1.1517	379	2.43
111	981.5H	-0.6957	0.7246	0.0344	-0.5839	328	3.38
112	1001.5H	-0.5144	0.2283	0.1536	0.9346	357	4.4
113	1021.5H	-0.596	-0.5946	0.1117	-0.6642	368	3.29
114	1048H	-0.6185	-1.0385	0.1915	-1.4177	402	2.09
115	1068H	-0.5751	-0.1429	0.1398	-0.0037	404	4.36
116	1088H	-0.6053	-0.2917	0.1267	-0.3647	381	3.76
117	1108H	-0.4263	-0.8319	0.2563	0.257	366	2.97
118	1128H	-0.62	-0.8428	0.1467	-1.0366	356	2.62
119	1340H	-0.5113	-0.2871	0.2468	0.7449	345	3.93
120	1345H	-0.5615	-0.4231	0.2259	0.0971	401	4.08
121	1350H	-0.5482	-0.429	0.2241	0.0628	373	3.77
122	1355H	-0.4783	-0.2191	0.2751	0.976	411	3.91
123	1360H	-0.5975	0.1988	0.1593	0.1605	379	4.52
124	1365H	-0.5709	-0.4389	0.2116	-0.0804	367	3.82
125	1370H	-0.5468	-0.453	0.2302	0.043	368	3.79
126	1375H	-0.5514	-0.7717	0.2432	-0.2549	396	3.12

Stratigraphy Key



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

1. Gastropods
2. Fine silt with gastropods
3. Coarse silt
4. Silt and Clay
5. Fine silt and organics
6. Banded silt/clay with gastropods
7. Silt/clay and organics
8. Clay, organics and gastropods
9. Sandy clay, organics and gastropods
10. Fine sand
11. Sandy clay and roots
12. Sand/silt with carbonate clasts
13. Mottled sandy/silt
14. Sand, gastropods and organics
15. Sand and gastropods
16. Clay

Hillbank 1998 Stratigraphy

Depth (cm)	Description
0-40	Clay with organics
40-183	Clay, sand and gastropods
183-310	Sand, gastropods and scattered organics
310-358.5	Clay and sand
358.5-440	Sand and gastropods
440-544	Clay and sand
544-630	Sand and gastropods
630-811.5	Sand and clay
811.5-941.5	Sand, clay and gastropods
941.5-1128	Clay and sand
1128-1198	Sediment missing
1198-1222	Fine clay
1222-1234	Banded silty clay
1234-1241.5	Silty clay with gastropods
1241.5-1290	Banded silty clay
1290-1340	Sediment missing
1340-1386	Silty clay

Stratigraphy of Hillbank 2000

Depth cm	Munsell Code	Colour	Description
0-9	10 YR 3/3 7.5 YR 5/2	Dark brown Brown	Smearing of darker section down to 18.5cm. Moussy sediment with large organic fragments (notably at 4-6, 9-10cm) 6-7cm – small shell new species. Mid section has lighter patches
9-12/14	7.5 YR 3/2	Dark Brown	Darker section, more uniform in colour. Same moussy texture. Diffuse boundary to next layer.
12/14-23.5	10 YR 5/2	Greyish brown	Lighter section with organic fragments (18.5-19.5, 21.5-22.5), same moussy, moist texture as above.
23.5-30	10 YR 4/1	Dark grey	4cm wide section on far side of core, sticky plastic clay with a few shells present at the base.
23.5-70	2.5 Y 6/2 2.5 Y 7/3	Light brownish grey Pale yellow	Central area darker and more moist than the edges, few scattered shells, some roots at the bottom of the record.

Lamanai 1999 2/1

0-42 cm

Depth (cm)	Munsell code	Colour	Comments
0-9	10Y 6/1	Greenish grey	Moist. Few coarse grains which may have been washed in. Rootlets. V Fine texture
9-21	10 Y 7/1	Light greenish grey	Less moist than above. Abundant gastropods, husk of a brown root at 19-20cm
21-25.5	2.5Y 7/3	Pale yellow	Gastropod layer, sediment has the same texture as above layer
25.5-27.5	2.5 Y 7/2	Light grey	Same texture, no visible gastropods
27.5-29.5	2.5Y 6/2	Light brownish grey	Distinct dark band with abundant gastropods
29.5-42	Top: 10YR 7/2 Base 2.5 Y 6/2	Top: light grey Base: light brownish grey	Colour and texture grades through getting coarser and darker. Gastropods throughout.

Lamanai 1999 2/2
0-89 cm

Depth (cm)	Munsell Code	Colour	Comment
0-30	2.5 Y 6/2	Light brownish grey	Fine silt: similar to above 26-27cm – shell layer
30-33	2.5 Y 6/2	Light brownish grey	Distinct shell layer
33-67	2.5 Y 4/2	Dark brownish grey	Darker section, slightly sticky silt/clay 41-42cm – organic traces
67-79	2.5 Y 6/3	Light yellow brown	Distinct lighter band, coarse silt. 70.5 –71.5cm – large shell. 78.5cm – organic trace: 10 YR 3/3 dark brown
79-89	2.5 Y 5/2	Greyish brown	Silt with a coarser fraction

Lamanai 1999 2/3 0-91cm

Depth (cm)	Munsell Code	Colour	Comment
0-31	10YR 5/2	Greyish brown	Fine silt, moist, shells visible from 18cm onwards, distinct band 22-23cm.
31-35	2.5Y 5/2	Greyish brown	Same texture, shells present. 31-32-darker lens (2.5Y 3/2 very dark greyish brown, same texture) does not extend full width. Very fine roots below this lens.
35-37	2.5 Y 5/3	Light olive brown	Same texture.
37-40.5	2.5 Y 5/2	Greyish brown	This is a darker band. Shells visible, same texture.
40.5-43.5	2.5 Y 6/3	Light yellowish brown	This is a light band, few visible shells, same texture. 41cm – very fine darker band
43.5-45.7	2.5Y 5/2	Greyish brown	This is a darker band, moister than the level above but the same basic texture.
45.7-47	2.5 Y 6/3	Light yellowish brown	This is a lighter band but moist with same texture as the above layer.
47-49.5	2.5 Y 5/2	Greyish brown	Distinct shell layer, quite a diffuse boundary. Texture difficult to define as the coarser fragment could be broken shells.
49.5-57.5	2.5 Y 6/2	Light brownish grey	Very greasy feel.
57.5-58	2.5 Y 5/3 2.5Y 4/2	Light olive brown Greyish brown	This darker band is discontinuous between the two colours. Same texture as above.
58-61	2.5 Y 6/2	Light brownish grey	Very greasy feel
61-62	2.5 Y 5/3	Light olive brown	Slightly coarser
62-83.5	2.5 Y 6/2	Light brownish grey	63cm – shells and organic Dark staining 70.5 / 69.5cm Organics – 80.5,82, 82.5 Coarser fraction lost.
83.5–84.5	2.5Y 4/2	Dark greyish brown	Very dark organic layer, lots of root hairs. Munsell code is the background colour
84.5-91	2.5 Y 5/2	Greyish brown	85.7-86 – organics

Lamanai 1999 2/4 0-97cm

Depth (cm)	Munsell Code	Colour	Comment
0-10.5 / 13	2.5 Y 6/2	Light brownish grey	Coarse silt, 8-11.5 – shell and root zone
10.5/13 -15	2.5Y 5/2	Greyish brown	Very fine texture
15-15.5	2.5 Y 4/2	Dark greyish brown	Darker band, same texture – silt/clay
15.5-16.5	2.5 Y 6/3	Light yellowish brown	Lighter band, texture as above
16.5-20.5	2.5 Y 6/2	Light brownish grey	19.5 – organic, texture as above, shells below the organic and occasional fine root hairs
20.5-22	2.5 Y 4/2	Dark greyish brown	Dark stain, fine root hairs
22-32	2.5 Y 6/2	Light brownish grey	Same texture, organic – 31cm, 32cm-3mm wide root running along width
32-35.5	2.5 Y 6/2	Light brownish grey	Same texture
35.5-46	2.5 Y 6/2	Light brownish grey	Clear tough organic layer – 39cm Thinner organic layer – 46cm
46-52	2.5 Y 5/2	Greyish brown	Darker band, few shells, same texture.
52-63	2.5 Y 7/2	Light grey	Light band, light yellow root 3mm wide running along width, same texture.
63-64.5	2.5 Y 6/2	Light brownish grey	Shell fragments, same silty/clay texture
64.5-67	2.5 Y 5/2 2.5 Y 4/1	Greyish brown Dark grey	Darker patch does not extend across, no textural difference
76.5-89	2.5 Y 5/1	Grey	80,82cm – organics
89-90	2.5 Y 5/2	Greyish brown	Lighter band, same texture
90-93	2.5 Y 5/1	Grey	Darker band, same texture
93-94	2.5 Y 6/2	Light brownish grey	Light band, same texture.
94-97	2.5 Y 5/2	Greyish brown	Contains a fine light layer

Outpost 2000 Stratigraphy

Depth (cm)	Munsell Code	Colour	Description
0-6	10 YR 6/2	Light brownish grey	Moussy clay, organic fragments, few shells present.
6-13.5	2.5Y 5/3	Light olive brown	Large organic fragments, large shell, same moussy clay but smaller silt fraction present.
13.5-19	10 YR 6/3	Pale brown	Few small shells present, same moussy texture, silt fraction same as above.
19-21.5	10 YR 6/2	Light brownish grey	Darker band, moussy texture with no silt fraction.
21.5-23.5	2.5 Y 5/2	Greyish brown	Distinct darker band, few very small organic fragments.
23.5-74	10 YR 6/3	Pale brown	Uniform sediment, organic fragments, moussy sediment with a silty fraction, lots of small shells.

Honey Camp Lagoon 1999 2/1 0-100cm

Depth	Munsell Code	Colour	Description
0-4/9	2.5 y 6/2	Light brownish grey	Litter fragments at the top, shells and shell fragments. Moist Clay. Fine root material common
4/9-15	10 YR 4/2	Dark greyish brown	Sharp boundary, more organic layer, lots of partly decayed organic matter (some quite coarse). Shells present (more than above)Quartz clast 5mm wide at 6.5cm More silt
15-23	10YR 6/2	Light brownish grey	Diffuse boundary, very sandy clay, gastropods, occasional organic matter
23-30	10YR 7/2	Light grey	Diffuse boundary, sandy clay, organic fragments, gastropods, medium root fragments common, occasional very fine roots quartz clast 2mm at 29cm (well rounded)
30-40	2.5 Y 7/2	Light grey	Fairly abrupt boundary, moist sand, coarse organic fragments common, gastropods, large shell – 36-39cm
40-73	Gley 10Y7/1 2.5Y 8/2	Light greenish grey Pale yellow	Fine sand, small sedimentary clast at 64.5cm 2mm wide, root fragment 60-62cm, occasional scattered medium/fine root fragments. Pale yellow found in slight bands – 10% of section
73-77/80	2.5 Y 8/2	Pale yellow	Abrupt boundary, clayey sand with a high fine fraction, occasional root hairs (medium and fine) 75.5cm sedimentary clast – taken out for analysis
77/80-100	Gley 10Y 7/1 10YR 8/2	Light greenish grey Very pale brown	Similar to 40-73cm, much more sand than 73-80cm Coarse roots, channel with fragments remaining through the section, lighter patches in discrete zones

Honey Camp Lagoon 1999 2/2 0-100cm

Depth	Munsell Code	Colour	Description
0-2	2.5 Y 8/2	Pale yellow	Large carbonate clast 30x25x20 (reacts with 10% HCL) within a sand/silt mix
2-35	5 Y 7/1 2.5 Y 8/2 5 PB 2.5/1	Light grey (88%) Pale yellow (7%) Bluish black (5%) (old root channel)	Abrupt boundary, more clasts up to 10mm across 3/4cm, 45cm, 32.5-33cm (5mm) banded clay especially at the top (up to 10-11cm) occasional fine root fragments up to 2cm long mixture of sand and silt.
35-41	2.5 Y 8/2 10 YR 7/4	Pale yellow Very pale brown (10%)	Abrupt boundary coarser than above, several clasts up to 20mm across, rare medium roots
41-56	10 YR 7/4 5Y 7/1 2.5 Y 8/2 5 PB 2.5 /1	Very pale brown Light grey Pale yellow Bluish black	Abrupt boundary, back to 2-35cm unit, occasional roots with black staining around pale brown mottles more obvious than in the original unit, silt/sand – more silty than original
56-68/73	10YR 8/2 5 Y 6/3	Very pale brown Pale olive (10%)	Massive silty clay, very fine
68/73-100	2.5 Y 6/6 10 YR 8/2 10 Y 8/1	Olive yellow (7%) Very pale brown Light greenish grey (main)	Massive clay, very fine flecks of black, orange mottles at the base (87-89cm), white mottles (5%), 75.5-79 – pale section (vpb)

Honey Camp Lagoon 1999 2/3 0-100cm

Depth	Munsell Code	Colour	Description
0-1			Tube empty
0-10.5	5Y 7/1	Light Grey	Moist sand/silt mixture
10.5-21	10 YR 8/2 5 Y 7/2	Very pale brown Light grey	Moist, sticky silty clay very soft
21-34/41			Moist sand silt mixture, tube is not filled, very watery at the bottom, occasional sedimentary clasts
34/41-47/49			Gap
47/49-52/54	10 YR 6/8	Brownish yellow	Moist sand silt mixture with occasional sedimentary clasts and orange mottles
52/54-100	10 Y 8/1 10 GY 7/1 5G 4/2 10 YR 6/8 2.5 YR 4/3 2.5 YR 4/6	Light greenish grey Light greenish grey Greyish green Brownish yellow Reddish brown (92-94cm) Red (97-98cm)	Massive mottled clay, very small holes throughout, white clasts, dark green mottles in a pale grey matrix which grades into a green matrix at 58cm, orange mottles and red mottles 87-88 – fine black line carbonates run below this. 40% mottles, quartz clast 99-100 cm 4mm across

Honey Camp Lagoon 1/1

Depth	Munsell Code	Colour	Description
0-3	2.5Y 7/1 10 YR 6/2	Light Grey Light brownish grey	Moussy texture, few scattered shells, light brown patches
3-5.5	10 YR 6/2	Light brownish grey	Light brown band with scattered shells, ends in black decomposing leaves in a layer
5.5-17	10 YR 7/2 2.5 Y 5/2	Light Grey Greyish brown	Few scattered shells, very fine bands at 9 and 11 cm
17-18.5	5 Y 5/2	Olive Grey	Very fine organic bands, could indicate shallowing
18-5-21.5	10 YR 6/2	Light brownish grey	Very fine, faintly laminated, occasional shells
21.5-30	10YR 5/2 7.5 YR 3/3 2.5Y 3/1	Greyish brown Dark brown (f) Very dark grey (f)	Increase in shells, distinct organic flecks up to 1cm across – mini layers? Moussy texture
30-32	10 YR5/2	Greyish brown	Brown band with occasional shells, much more uniform than layer above
32-35	10YR 6/2 10 YR 7/2	Light brownish grey Light grey	At 32mm 2mm thin band
35-36	7.5 YR 5/2	Brown	Brown band, shells
36-37.5	7.5 YR 6/2	Pinkish Grey	Shells

Honey Camp Lagoon 4/1

Depth	Munsell Code	Colour	Description
0-1	5Y 8/1 5 YR 5/4	White Reddish Brown	Very fine moussy sediment
1-9	5Y 7/1	Light grey	Uniform, very fine
9-10	5Y 6/1	Grey	Band
10-12.5	2.5Y 6/1	Grey	Band with shells, darker than one above
12.5-13	2.5Y 7/1	Light grey	Pale band
13-13.5	2.5Y 5/1	Grey	Darker band
13.5-14	10Y 7/1	Light grey	Pale band
14-15	2.5Y 6/1	Grey	
15-17	2.5Y 7/1	Light grey	
17-18.5	5Y 6/1	Grey	Darker band
18.5-19.5	5Y 6/2	Light olive grey	Pale band
19.5-21	5Y 6/1	Grey	Darker layer, few shells
21-21.2	5Y 7/2	Light grey	Very fine pale lens
21.2-22.5	5Y 4/1	Dark grey	
22.5-23	2.5Y 7/1 2.5Y 3/1	Light grey Very dark grey	Pale layer with organic layers/flecks
23-24	5 Y 4/1	Dark grey	Very dark layer with shells
24-26	2.5Y 7/1	Light grey	
26-27	2.5 Y 7/2	Light grey	Slightly pinker layer
27-28	5Y 6/2	Light olive grey	Darker layer
28-29.5	2.5Y 7/1	Light grey	Pale layer
29.5-30	2.5Y 5/1	Grey	Darker layer
30-34	5Y 6/2	Light olive grey	Few shells, uniform
34-36	5Y 5/2 5Y 2.5/2	Olive grey Black	Increase in organic flecks within matrix
36-38.5	5Y 6/1	Grey	Uniform
38.5-45.5	5Y 4/2 5Y 3/2	Olive grey Dark olive grey	Increase in organic flecks and number and size of shells
45.5-46.5	5Y 6/1	Grey	Possible contamination at the bottom

Depth	Munsell Code	Colour	Description
0-4	2.5Y 7/1	Light Grey	Very fine silt/clay, moussy texture with scattered gastropods
4-7.5/11.5	7.5YR 6/2	Pinkish Grey	Very fine sediment with scattered gastropods
7.5/11.5-8/12	2.5 Y 7/1	Light Grey	Thin diagonal band
8/12-18	10 YR 7/1 5YR 6/2 7.5YR 4/1 10 YR 7/1 10YR 6/1	Light Grey Pinkish Grey Dark Grey Light Grey Grey	Colour at top of section 12cm: dark band 2-3mm wide Colour in between the two dark bands 15cm: dark band 2-3mm wide Zone in between From 17cm dark grey discontinuous band
18-19.5	7.5 YR 6/2	Pinkish Grey	Same texture as above with scattered gastropods
19.5-20	7.5 YR 3/1	Very dark Grey	Dark band with woody fragments < 1mm long
20-21.5	10YR 6/1	Grey	Slightly darker band which is discontinuous at base of layer. Scattered gastropods
21.5-26.5	2.5Y 6/1 5YR 5/2	Grey Reddish grey	Scattered gastropods Discontinuous fibrous band at 23.5cm
26.5-28.5	5YR 5/3	Reddish Brown	Dark organic band full of gastropods Same texture as above
28.5-30	2.5Y 7/1	Light Grey	Coarser than above
30-79	2.5Y 7/1	Light Grey	Continuous grey sediment with high levels of gastropods throughout

Stratigraphy for Honey Camp 2000

Appendix 7

One of the issues that has been raised in this thesis is that the taxonomy of tropical species may not be exactly the same as those detailed in European floras. *Mastogloia smithii* var. *lacustris* was investigated in Chapter 5 and was found to have some important distinctions to both the published and type material. Two further species are also of interest: *Cyclotella distinguenda* and *Cyclotella plitvicensis*. According to Hakansson (1989) the key feature which distinguishes these two species is the lack of undulation on the central part of the valve face in *C. plitvicensis*. Under the light microscope although it was apparent that there were two different forms of *Cyclotella* in the samples, the valve margins could not be categorised in this way. As a result the samples were examined under a Scanning Electron Microscope (SEM).

Cyclotella distinguenda:

Characteristics: Hustedt (1927) (in Hakansson, 1989) described *C.distinguenda* as being 10-35µm in diameter, having an undulate centre to the valve face with 12-14 striae in 10µm. The central zone was described as smooth or irregularly punctate.

The reference material with which the Belizian examples were compared against was Krammer and Lange-Bertalot (1991) plate 43 and the written description. The key characteristics that match are (when looking under the SEM):

1. The central area is punctate with occasional fultoportulae.
2. The central area is formed from a convex raised undulation (this is only noticeable under SEM)
3. The structure of the striae match with rows of areolae increasing in number on the mantle.

There are some discrepancies though:

1. The published description of *Cyclotella distinguenda* has a fultoportulae every third costae. The Belizian form is at a greater frequency to this.
2. Samples from Spain analysed by Jane Reed have several fine areolae between costae (Reed, pers.com.). In the Belizian samples these are found at a much lower frequency. This may be due to dissolution.
3. It is difficult to find evidence for the openings of the fultoportulae on the external view of the Belizian samples. This may also be related to dissolution.
4. The Belizian examples do not show a smooth boundary between the central area and the striae.

From this it is apparent that the Belizian samples are very close but not exactly the same as the published form.

Cyclotella plitvicensis:

This was described by Hustedt in 1945 (Hakansson, 1989). This species was described as having a diameter of 12-40µm, with a flat valve centre and more widely spaced striae in the marginal zones (8-10 in 10µm). Despite the differences between this species and *C.distinguenda* they are thought to be found in the same ecological conditions. The examples from Belize do match the published description.

The significance of the difference is therefore difficult to ascertain especially as the species were not found in the modern Belize samples and therefore their ecological tolerances could not be judged.

The following plates illustrate the points raised above.

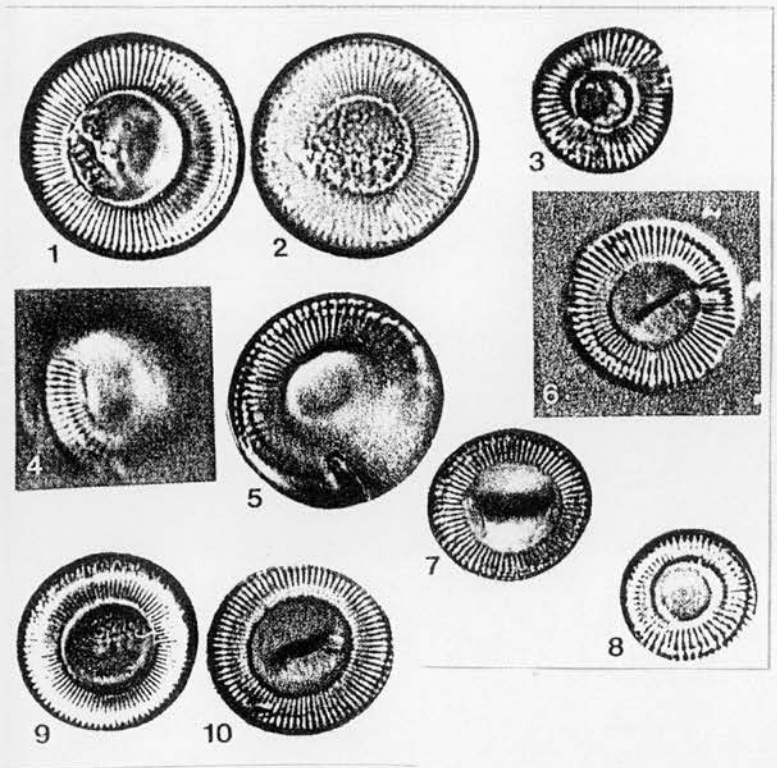
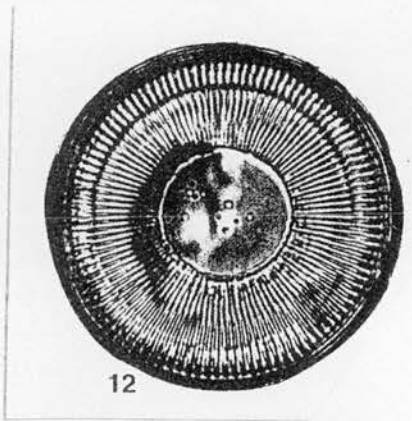
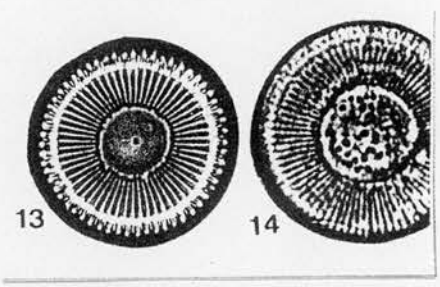
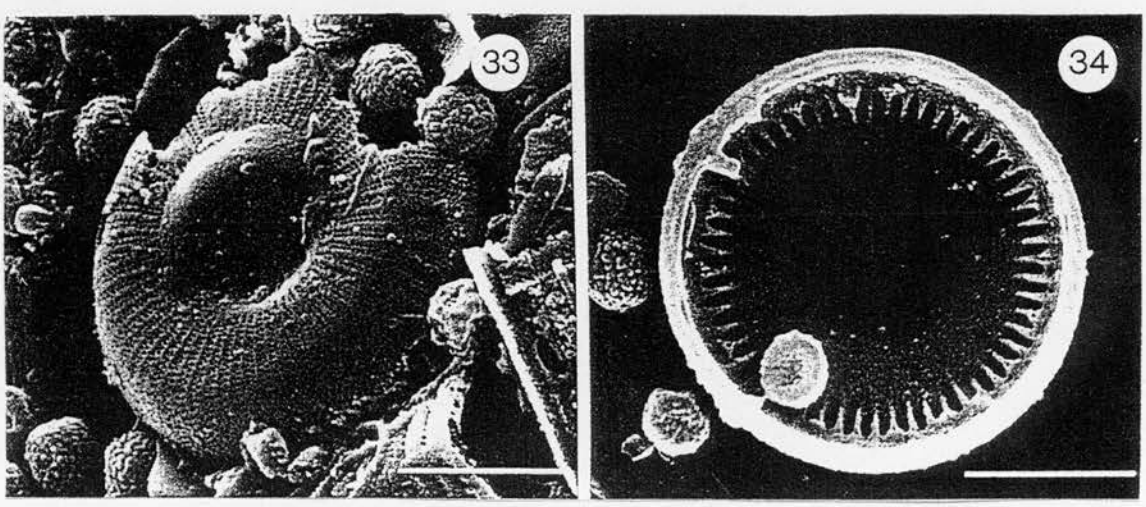


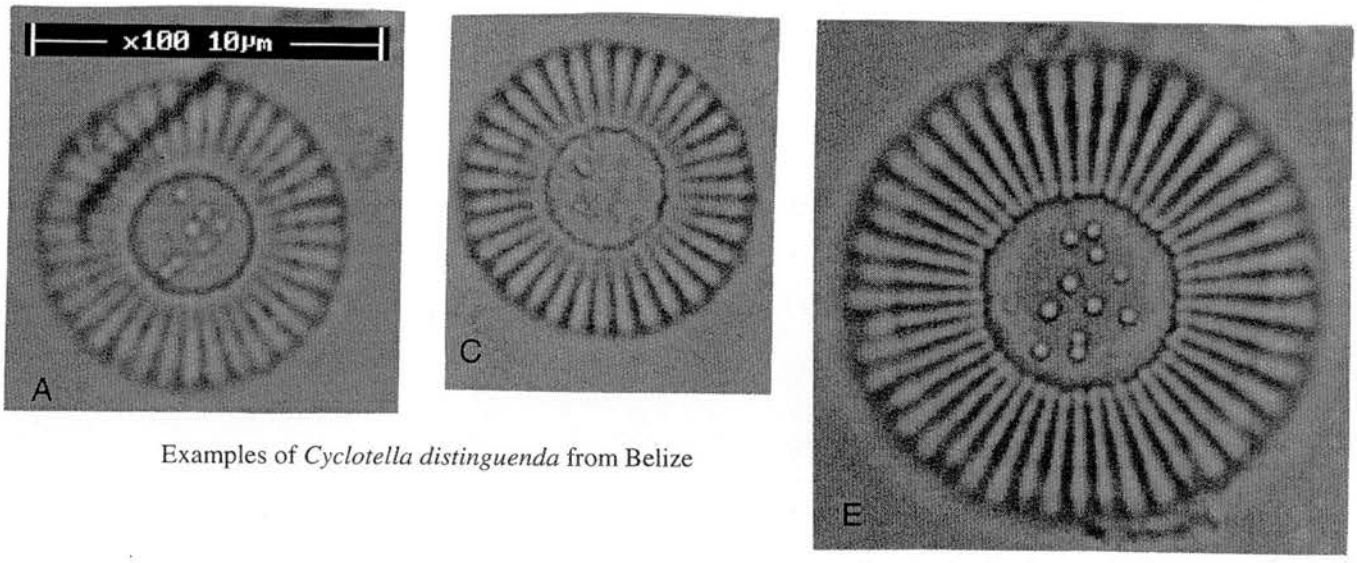
Plate 43 from Krammer and Lange-Bertalot (1991)
1-10: *Cyclotella distinguenda*
12-14: *Cyclotella plitvicensis*



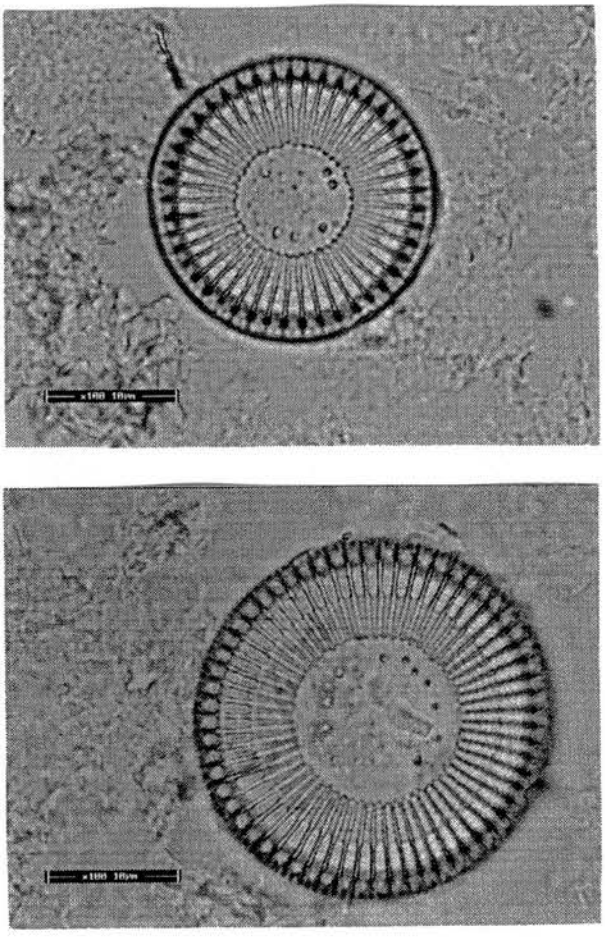


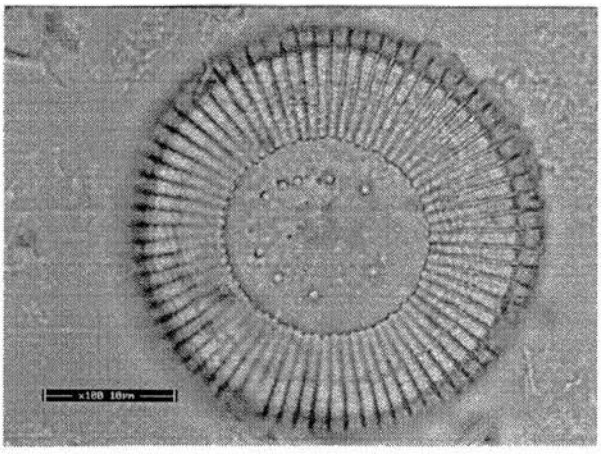


Cyclotella distingeunda (external and internal view SEM) from Hakansson (1989)

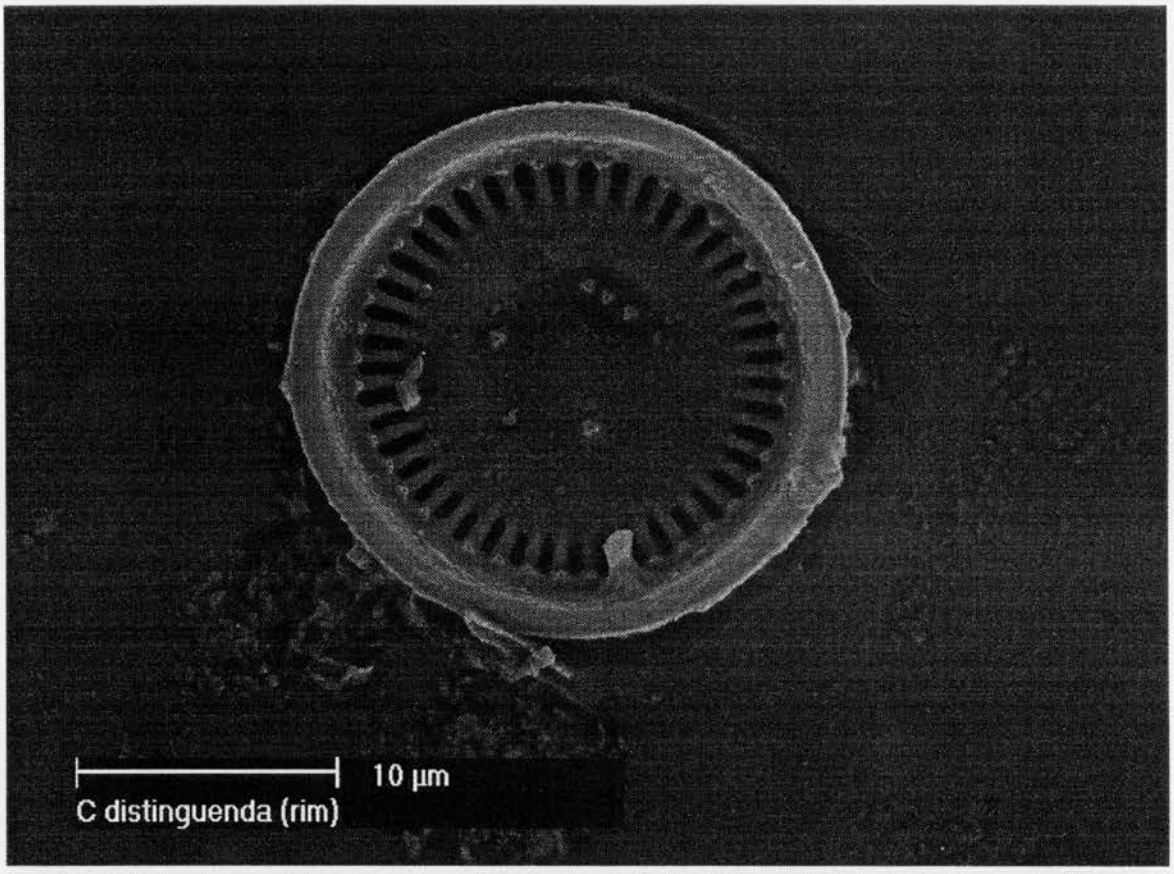


Examples of *Cyclotella distinguenda* from Belize

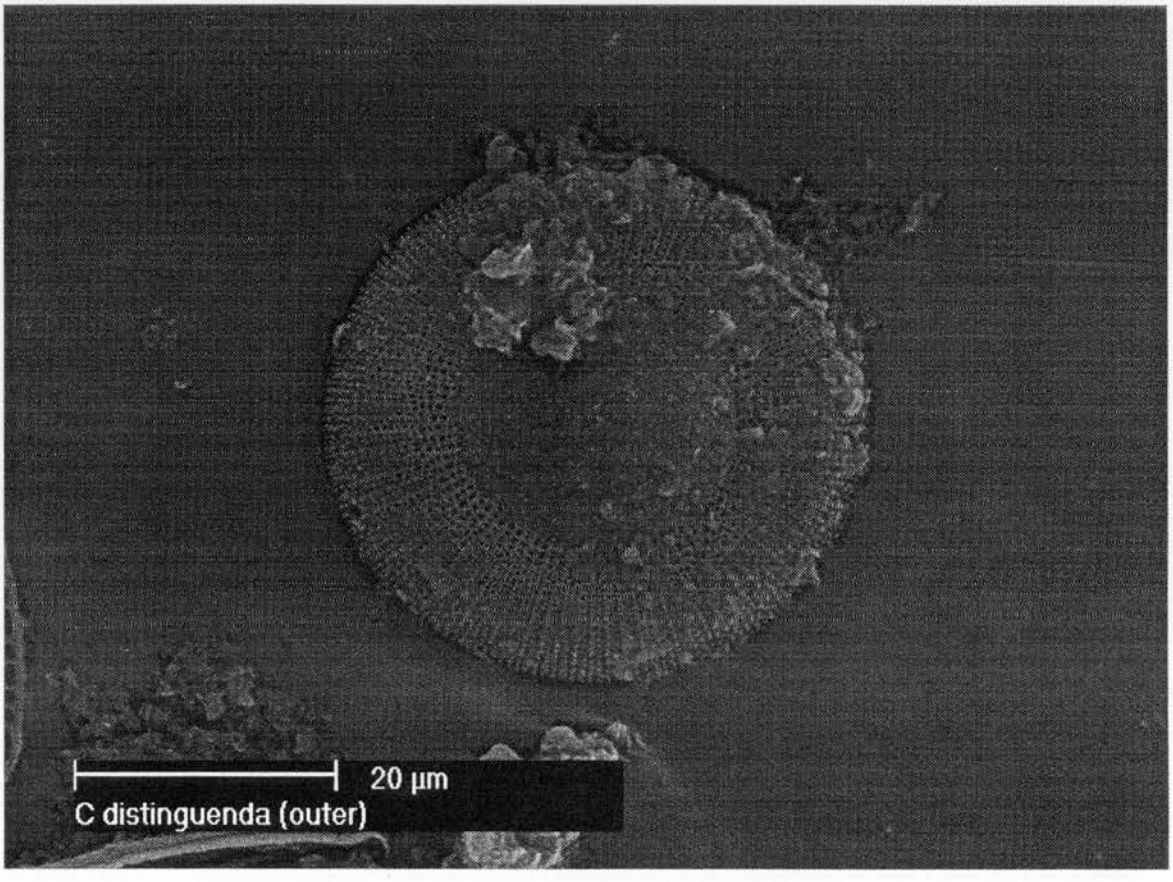




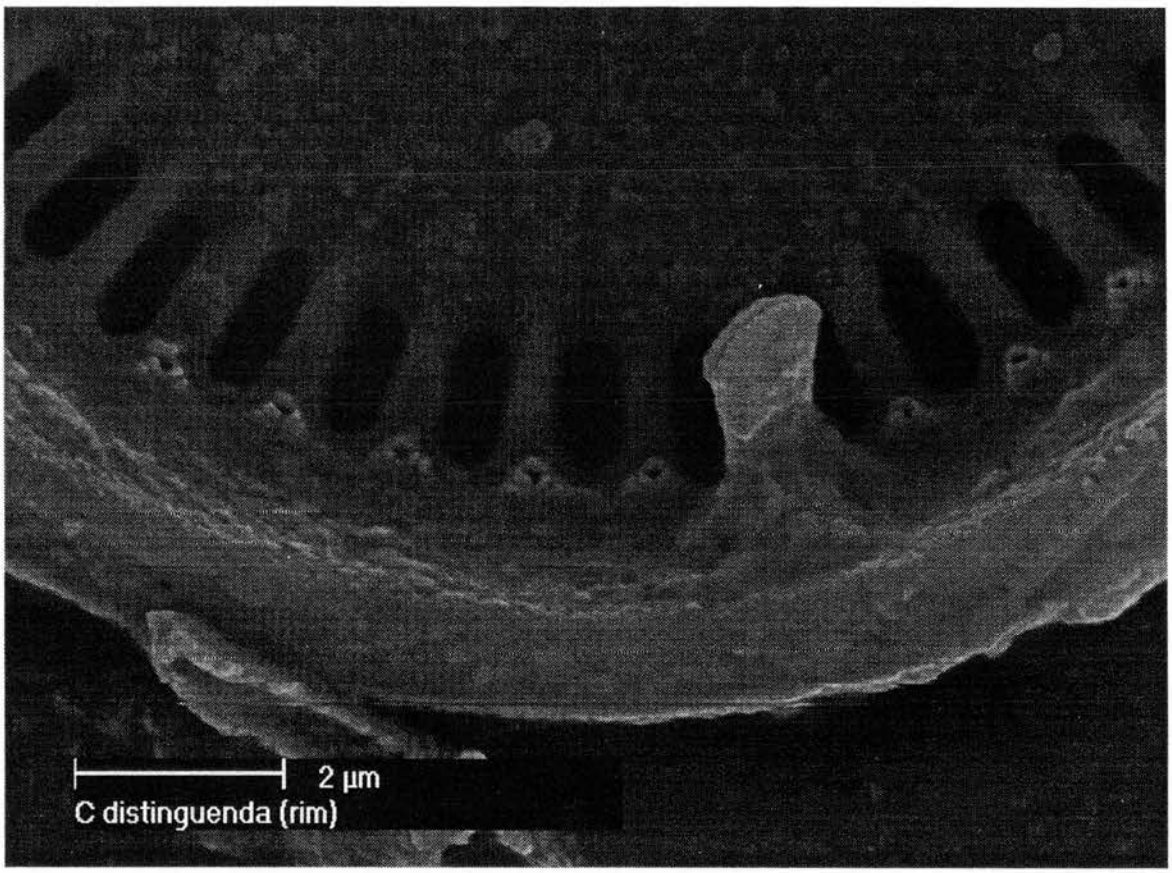
Examples of *Cyclotella plitvicensis* from Belize



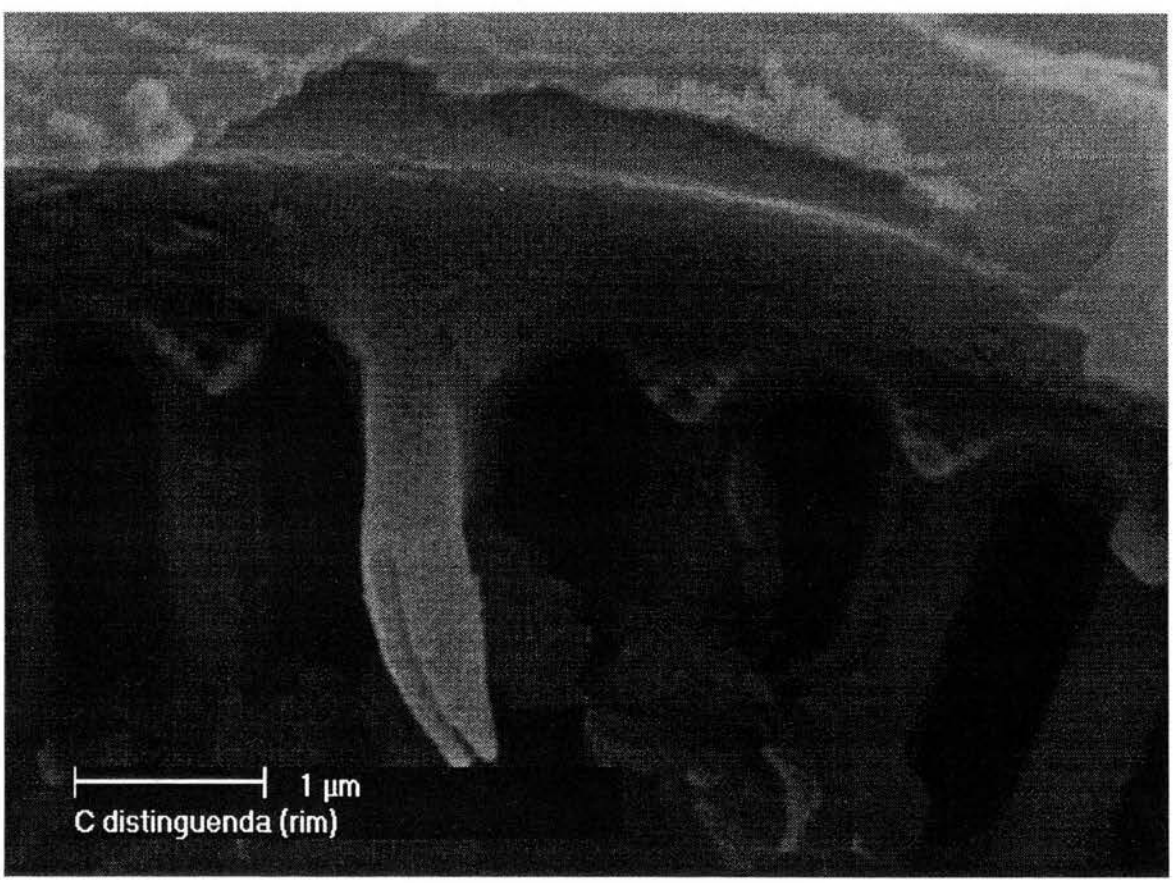
Internal view showing rimportula, fultoportulae around the rim and in the centre

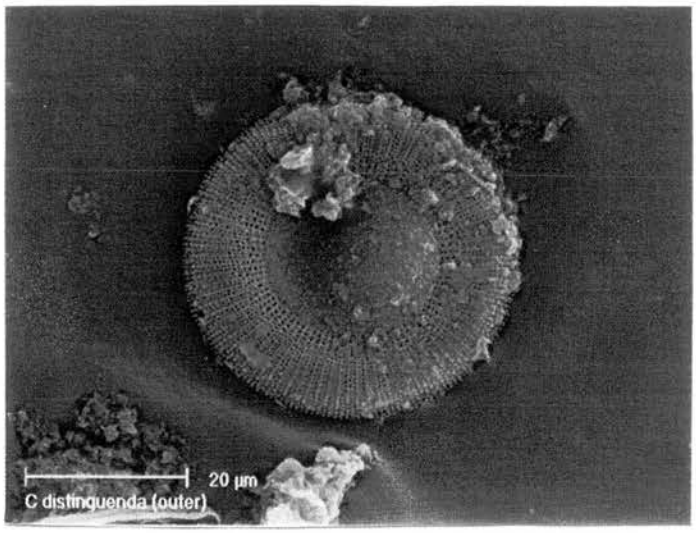


External view showing undulate central area

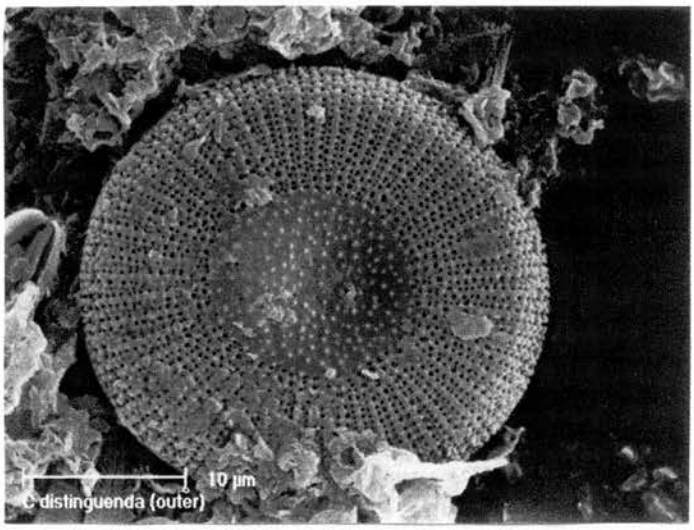


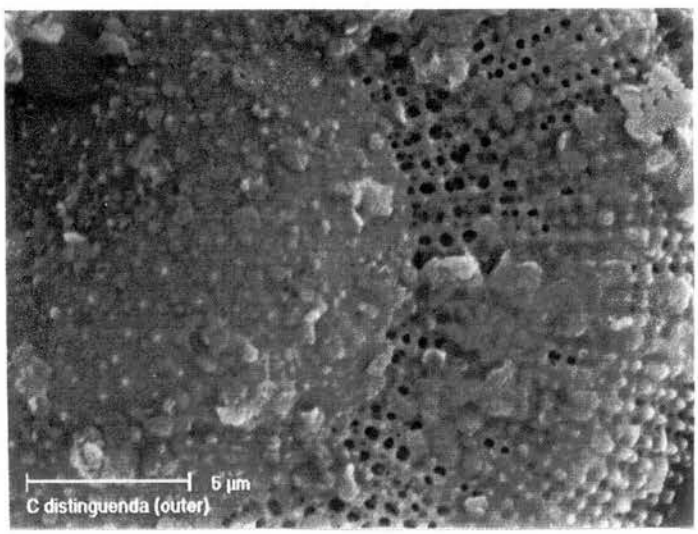
Examples of rimportulae





Examples of undulated central area in Belizian *Cyclotella distinguenda* (SEM). This feature is much harder to differentiate under LM.





An example of the Belizian *Cyclotella distinguenda* showing that the central area boundary is not smooth.